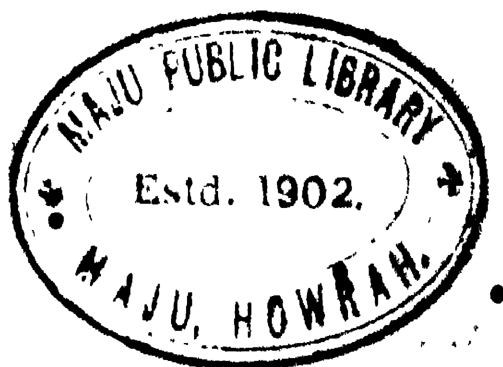
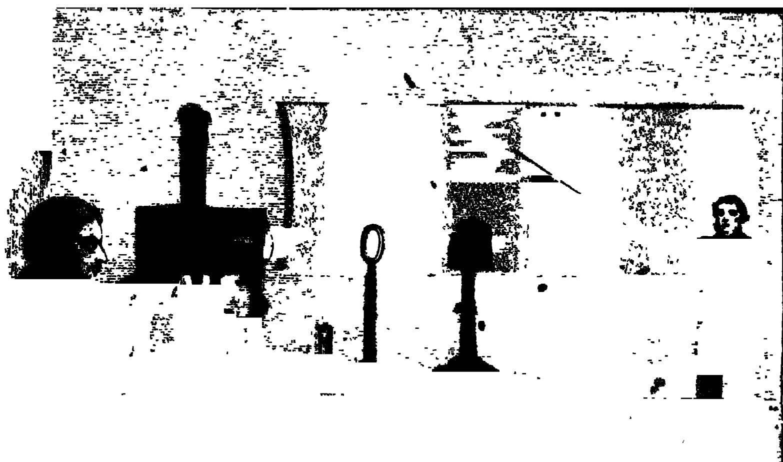






SPECTRUM ANALYSIS,

Exhibited at the Royal Polytechnic Institution, London

1. SIMPLE SPECTRUM. 2. SILVER 3. THALLIUM.

CYCLOPÆDIC SCIENCE SIMPLIFIED.

J. H. PEPPER,

Of the Royal Polytechnic Institution, Fellow of the Chemical Society, Associate of the Institution of Civil Engineers; Author of various Works for Youth, &c.

EMBRACING

LIGHT
- Reflection and Refraction of Light
- Light and Colour
- Spectrum Analysis
- The Human Eye
- Polarized Light

HEAT
- Thermometric Heat
- Conduction of Heat
- Latent Heat
- Steam

ELECTRICITY
- Voltaic, Galvanic, or Dynamical Electricity

MAGNETISM
- Electro-Magnetism, Magneto-Electricity, Thermo-Electricity
- Dia-Magnetism
- Wheatstone's Telegraphs

PNEUMATICS
- The Air-Pump
- The Diving-Bell

ACOUSTICS
- The Education of the Ear

CHEMISTRY
- Elements which are not Metallic
- The Metals

WITH NUMEROUS ILLUSTRATIONS.

REVISED EDITION.

1902.

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INTRODUCTION.

IN the Author's earlier works, written only for the youthful student in Science, a promise was made that other books, to be regarded as a series of steps in Science, should be forthcoming.

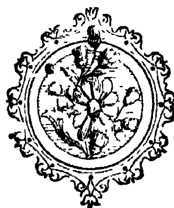
It is with this view that the present volume is offered; and as the general reader—in fact, "the Public"—has not the time or the inclination to study the very minute and laborious works of GMELIN, WATT, MILLER, and other learned authors, it is hoped that the facts contained in this more advanced but still elementary work will be found sufficiently attractive to stimulate, at all events, the would-be philosopher to further reading, and especially to perform correct scientific experiments.

Brevity and simplicity have been carefully attended to in the following pages; and when other authors are quoted, the writer has preferred giving their exact language, instead of altering and paraphrasing words, which frequently detracts from the sense of the passage.

The reader will find portions of valuable papers written by

FARADAY, DANIELL, WHEATSTONE, BREWSTER, TYNDALL, CROOKES, BROWNING, SIEMENS, NOAD, STEWART, TAIT, MARLOYE, and others, with a brief summary of Photography by JOHN SPILLER, Esq.

In a work like this, including such a multiplicity of subjects, the kind indulgence of the reader is invoked for any errors that the most painstaking supervision may have permitted to pass.

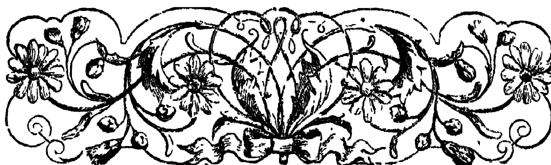


Dedication.

I dedicate this work, with all kindly feelings, to those students at Harrow, Eton, Hayleybury, and Cheam, to whom, under the auspices of the Rev. Drs. Vaughan, Goodford, Hawtrey, Butler, Bradby, and Tabor, I have addressed many lectures on Science.

I believe and trust that those lectures have not been altogether unfruitful; but that they have aided in the establishment of regular science classes for the present generation, instead of the desultory lectures at rare intervals to which custom formerly condemned the teachers of popular science.

JOHN HENRY PEPPER.



CONTENTS.

HEAT.

HEAT—continued.

ELECTRICITY.

ELECTRICITY—continued

MAGNETISM.

MAGNETISM—continued.

[MA]GNETISM—continued.

MAGNETISM—continued.

[P]NEUMATICS.

PNEUMATICS—continued.

[A]COUSTICS.

ACOUSTICS—continued.

[C]HEMISTRY.

CHEMISTRY—continued.

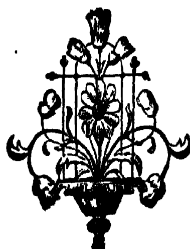
CHEMISTRY—*continued.*

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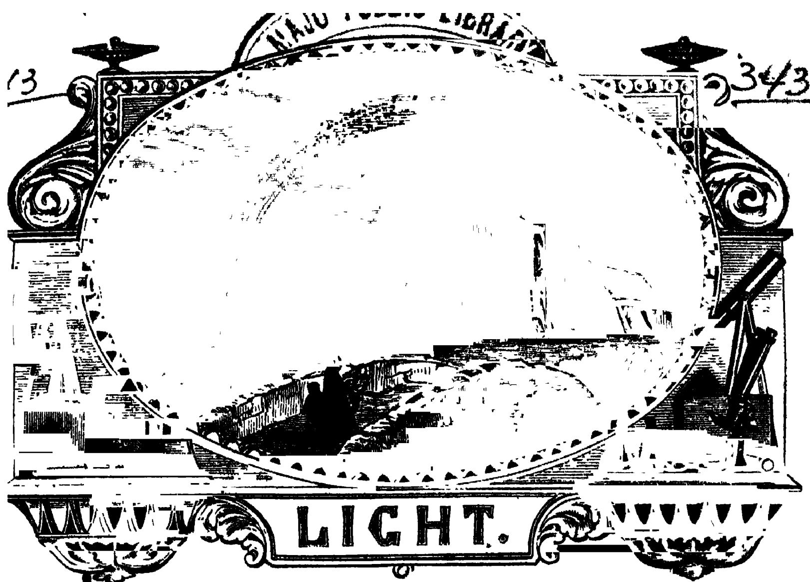
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)RGANIC CHEMISTRY.

ORGANIC



CYCLOPÆDIC SCIENCE SIMPLIFIED



ON LIGHT,

AND THE ETHER SUPPOSED TO PERVADE THE WHOLE UNIVERSE.

ABOUT two hundred years ago Descartes, Hook, and Huygens, three of the most celebrated mathematicians of their day, entertained the idea that light was propagated by the vibrations and undulations of a subtile elastic fluid called *ether*, which not only filled infinite space, but was contained in all solid, fluid, and gaseous bodies. The immortal Newton, who was opposed to this theory, or at least created one of his own, usually called the Corpuscular Theory of Light, appears to have entertained the opinion (according to Enfield) that "All fixed bodies, when heated beyond a certain degree, emit light and shine; and this emission is performed by the vibrating motion of their parts."

"The heat of a warm room is conveyed through a *vacuum* by the vibration of a much subtiler medium than air, which, after the air is drawn out, remains in the vacuum.

"It is by the vibrations of this medium that light is refracted and reflected, and heat communicated. This medium is exceedingly more elastic and active, as well as subtile, than the air; it readily pervades all bodies, and is by its elastic force expanded through the heavens. Its density is greater in free and open space than in compact bodies, and increases as it recedes from them. This medium, growing denser and denser perpetually as it passes from the celestial bodies, may, by its elastic force, cause the gravity of those great bodies towards one another, and of their parts towards the bodies. Vision, hearing, and animal motion may be performed by the vibrations of this subtile elastic fluid or ether."

These opinions would seem to show that Newton believed all emanations of particles of light were attended by the undulations of an ethereal medium accompanying it in its passage.

The theory, however, generally ascribed to him is, that rays of light are small corpuscles emitted with exceeding celerity, travelling at about the rate of one hundred and eighty-two thousand miles per second; and these rays of light, falling upon the eye, excite vibrations in the *tunica retina*, which, being propagated along the solid fibres of the optic nerve to the brain, cause the sense of sight.

Could Newton, who insisted so much on the importance of experimenting before enunciating a theory, have been acquainted with the highly interesting experiments connected with the inflection or diffraction of light, he would not have opposed the notion of an analogy between the phenomena of light and sound when he says: "The waves, pulses, or vibrations of the air, wherein sound consists, are manifestly inflected, though not so considerably as the waves of water; and sounds are propagated with equal ease through crooked tubes and through straight lines; but light was never known to move in any curve, *nor to inflect itself ad umbram*." This decided statement is directly contradicted by actual experiment, because light can be bent into or towards the shadow.

The corpuscular theory fails to explain that which is easily understood by the undulatory theory, and by analogy to waves of water or air, that two rays of light may come together in a special manner and produce *darkness*, just as two waves of water may interfere with each other and form a smooth surface, or two waves of sound produce silence. Dismissing the theory of Newton as we might pass by the venerable ruins of some ancient edifice, with mingled interest and regret, we may return to the consideration of the ether supposed to fill all space.

The great Dr. Franklin, in a letter dated 23rd April, 1752, throws out the suggestion that all the phenomena of light may be more conveniently solved by supposing universal space filled with a subtile elastic fluid, which when at rest is not visible, but whose vibrations affect that fine sense in the eye as those of air do the grosser organs of the ear.

Thornbury, Mitchell, and others, endeavoured to prove the materiality of light by showing that the corpuscles had a power of momentum which might affect other and very light substances. Could this fact have been really ascertained, there would be nothing more to say against Newton's hypothesis; but their experiments were illusory and useless. On the other hand, the supporters of the undulatory theory have within the last three years performed the most elaborate and exact experiments to try to prove the real existence of the ether. Mr. Balfour Stewart, F.R.S., superintendent of Kew Observatory, and Professor P. G. Tait, M.A., of Edinburgh, whilst leaving other scientific men to make their own deductions from the results they obtained, have called attention to the subject by a paper read before the Royal Society in June, 1865, and modestly entitled "On the Heating of a Disc by Rapid Rotation *in vacuo*." The authors, having obtained certain results in air, were encouraged to construct the apparatus as figured below, Fig. 1, wherewith to procure rotation *in vacuo*.

"In this apparatus a slowly revolving shaft is carried up through a barometer tube, having at its top the receiver which is to be exhausted. When the exhaustion has taken place, the shaft connected with the multiplying gear revolves in mercury. The train of toothed wheels causes the disc of alumi-

nium to revolve 125 times for each revolution of the shaft. The thermo-electric pile, the most delicate thermometer or test of heat, is connected by two wires carried through two holes in the bed-plate of the receiver with a Thompson's reflecting galvanometer needle (an instrument which is described and figured

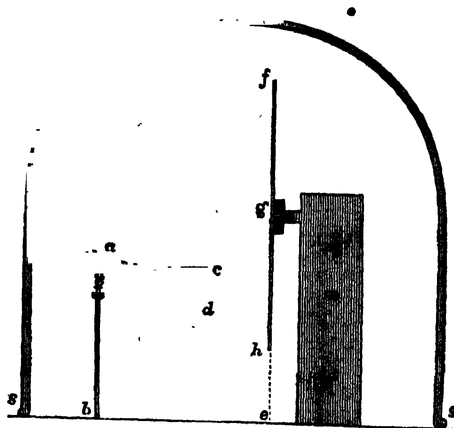


FIG. 1.

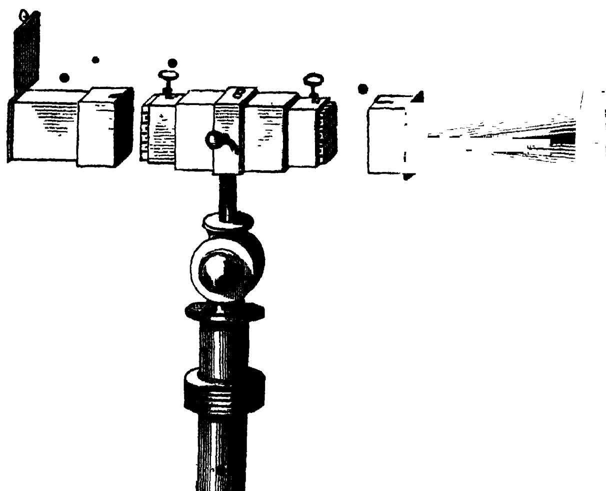


FIG. 2.

a, Figs. 1 and 2, thermo-electric pile with reflecting cone attached; *a b*, height 6 in. from bed-plate; *a c*, length of cone, &c., 5¾ in.; *c d*, diameter of the aperture of the reflecting cone 2½ in.; *f h*, the disc of aluminum 13 in. diameter; *e g*, height from bed-plate to centre of the aluminum disc 8½ in.; of the thermo-electric pile from the disc of aluminum 8 in.; *m*, base containing *s s s*, air-tight glass receiver, 15 in. diameter and 16 in. high, covering the whole.

in the article on Electricity in this work). The outside of the thermo-electric pile and its attached cone was wrapped round with wadding and cloth, so as to be entirely unaffected by currents of air.

"During these experiments the disc of aluminium was rotated rapidly for half a minute, and a heating effect was, in consequence of the rotation, recorded by the thermo-electric pile (an instrument described fully in the article on Electricity).

"To obviate the objection that the electric currents which take place in a revolving metallic disc might alter the zero of the galvanometer, the position of the line of light was read before the motion began, and immediately after it ceased, the difference being taken to denote the heating effect produced by the rotation.

"The thermometric value of the indications given by the galvanometer was found in this way:—The disc was removed from its attachment and laid upon a mercury bath of known temperature. It was then attached to its spindle again, being in this position exposed to the pile, and having a temperature higher than that of the pile by a known amount. The deflection produced by this exposure being divided by the number of degrees by which the disc was hotter than the pile, gives at once the value in terms of the galvanometric scale of a heating of the disc equal to 1° on Fahrenheit's scale.

"The disc of aluminium being blackened with a coating of lampblack, applied by negative photographic varnish, and rock salt inserted in the cone, the following results were obtained:

No of set.	No. of observations in each set.	Time at full speed.	Heat indications ° Fahrenheit.
I.	3	30	0·85
II.	4	30	0·87
III.	4	30	0·81
IV.	3	30	0·75

"To ascertain whether the radiant heat recorded was derived from the rock salt, or from heated air, or from the surface of the disc, the next series of experiments were tried.

EXPERIMENTS WITH BLACKED ALUMINIUM DISC WITHOUT ROCK SALT.

No. of set.	No. of observations in each set.	Time at full speed.	Heat indications ° Fahrenheit.
V.	3	30	
VI.	3	30	

"With certain modifications of the above experiments it was satisfactorily proved that the effect was not due to heating of the rock salt, or to radiation from heated air; it must therefore be due to the disc of aluminium, which seemed to have rubbed against some matter which remained in the receiver after the air was removed. The question being, was this *ether?*"

The authors further state that,

"1.—It may be due to the air which cannot be entirely got rid of.

"2.—It is possible that visible motion becomes dissipated by an etherial medium in the same manner and possibly to nearly the same extent as molecular motion, or that motion which constitutes heat.

"3.—Or, the effect may be due partly to air and partly to ether.

"Not to leave the matter wholly undecided, it was suggested by Professors

Maxwell and Graham that there is another effect of air, viz., fluid friction, the coefficient for which they believe to be independent of the tension.

"It would appear, however, that the fluid friction of hydrogen is much less than that of atmospheric air, so that were the heating effect due to fluid friction it ought to be less in a hydrogen vacuum. An experiment proved that the heating effect due to rotation in a hydrogen vacuum was 22·5, while in an air vacuum it was 23·5, and the authors are inclined to consider these numbers as sensibly the same, and that the experiment indicates that the effect is not due to fluid friction; at the same time they do not suppose that their experiments have yet conclusively decided the origin of this heating effect, but they hope to elicit the opinions of those interested in the subject, which may serve to direct their future research."

These experiments are more satisfactory than any previously tried, and, taken in conjunction with other facts, such as the temporary phosphorescence of certain bodies by what is termed insolation or irradiation, or the action of light in reducing certain salts to their metallic state, or the elaborate and beautiful effects obtainable from thin films of solid, fluid, and gaseous bodies, or the action of crystallized bodies on polarized light, they do altogether impress the reasoning faculties with a conviction that a vibrating motion accompanies the production of all light, which can only be propagated by the communication of these vibrations or tremblings to a medium, itself as subtile, rare, and exquisite as the delicate mechanism that sets it in motion.

Starting with the proposition that all sources of light and luminous bodies, like musical instruments, must first vibrate, it is not difficult to understand by analogy how these vibrations may travel at the rate of 182,000 miles per second, in straight lines, called rays.

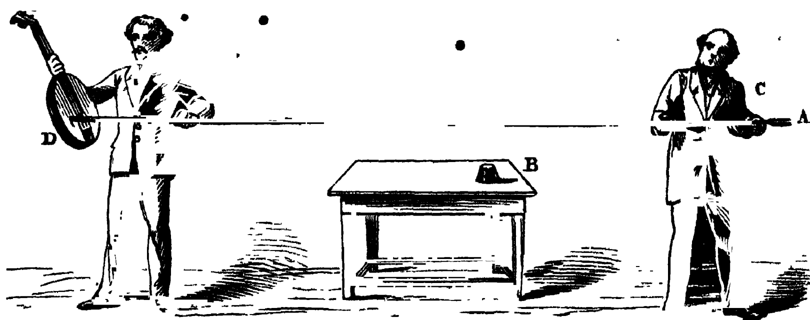


FIG. 3.

A, tuning-fork struck on the leaden cone B, capped with leather, and applied to the end of the rod C, whilst the other end is held against the sounding-board D.

A tuning-fork emitting sound might by analogy represent a source of light like the sun, whilst a long rod communicating with it would stand in the place of the theoretical ether, propagating the undulations from the sun through a space of 92½ millions of miles, and if the other end of the rod communicates with the sounding-board of a guitar, the audible sound obtained might compare with the light falling on the earth and becoming apparent by radiation.

The conversion of a continued series of mechanical impulses into waves is beautifully shown by taking hold of the end of a long vulcanized india rubber tube filled with sand, and having attached one end to the ceiling or other convenient place, it is easy by a jerk to produce the appearance of a wave, which travels distinctly from the hand to the ceiling; at the same time it demonstrates the progressive nature of the wave or undulation, and as the portion held by the operator cannot move from his hand to the ceiling, it shows how the eye is deceived whilst looking at the motion of waves of water. Every wave in water is propagated by the rising and falling of that which has preceded it, and not because the volume of water representing the wave travels bodily from the spot where it is first noticed to the shore where it breaks.

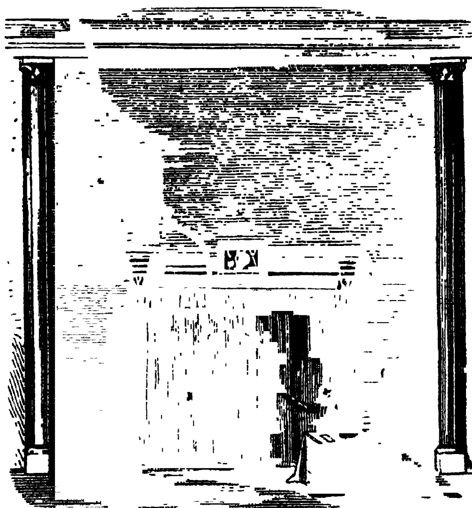


FIG. 4.—*The Vulcanized Tube attached to the ceiling, and thrown into protuberance or waves by the hand of the operator.*

Dr. Tyndall has shown, by a modification of Dr. Young's experiments with vibrating strings upon which light is thrown, a number of very beautiful effects. A silvered cord attached to the iron arm of a curved spring band, one end of which is made to vibrate by an electro-magnet, displays the divisions of the cords into wave-like figures most perfectly when the cord is illuminated by the lime or, better still, the electric light. (Figs. 5 and 6, p. 7.)

Using the brilliant light as before, a still more perfect and admirable experiment may be conducted by attaching one end of a bright silvered chain to a hook screwed into a vertical whirling table, and the other to a proper stand. The chain being horizontal and the wheel vertical, it may be swung into one long wave, or, by a still more rapid rotation, can be divided into three, four, or more. The links of the chain flash in the light, and produce the most pleasing effects.

It must be remembered that if cords, chains, water, air, &c., can assume a wave-like motion, the wonderful tension and elasticity of the hypothetical ether

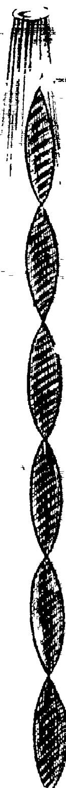


FIG. 5.—The Silvered Cord vibrating, and showing the beautiful gauzy spindles and wave-like figures.

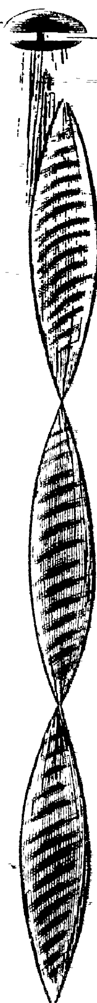


FIG. 6.—The Silvered Chain and Electric Light.

would permit the latter to adapt itself to the most complicated movements almost with the rapidity of thought. The very spiral, spindle-like, or cork-screw motion observable in the chain and cord affords a good idea of the mechanism of the propagation of light, as the movement of each molecule of ether is always perpendicular to the path of the ray or wave of light.

The astonishing rapidity of the periodic movements of the non-gravitating molecules of ether becomes apparent, when it is stated that to produce white light five hundred millions of millions of vibrations of the ether, 1,000,000,000,000 × 500 must occur in every second of time.

Or, taking the coloured rays at the extremities of the solar spectrum, viz., the red ray and the violet, the former demands the recurrence of four hundred and fifty-eight millions of millions, 1,000,000.000 000 × 458 ; and the latter, the violet, a still larger number, and greater rapidity of vibration, six hundred and ninety-nine millions of millions, 1,000,000,000,000 × 699 per second.

The coloured rays of light are supposed, according to the undulatory theory, to be distinguished from each by the breadths of the different waves, just as the sound of a stringed instrument may vary according to the diameter and thickness of the strings. A tightly-stretched thin cord vibrating would be the parallel to violet light. It is an axiom that, "*The rapidity of vibration is inversely proportional to the length and diameter of the string, and proportional to the square root of the tension.*" A thicker cord not so tightly stretched would be the parallel to red light.

SOURCES OF LIGHT.

At the various instrument-makers cases containing four or five tubes, filled with white powders and hermetically sealed, are to be obtained. When the tubes are observed in a dark room (and, of course, before exposure to light), they are invisible; if, however, a piece of magnesium wire is now burnt close to the tubes, they will be found to shine in the dark and to emit various coloured rays of faint light. To this curious effect is given the name of phosphorescence; and when the same result is obtained by exposing the tubes to the light of the sun, the resulting phenomenon is denominated phosphorescence after insolation, *i.e.*, after exposure to the sun. The chemical substances which possess the property of developing light after exposure to light are called phosphori, and the best are the diamond, Bolognian phosphorus, or Bologna stone, made from sulphate of baryta, which occurs in nature as a mineral, and is called heavy spar or barytine. It is prepared by heating this mineral with charcoal to a dull red heat, or by the process of Margraf, in which the mineral is powdered, mixed with flour, and made red hot; or more amusingly by the process of Daguerre, who uses a marrow-bone for his crucible, and, after it is freed from fat and thoroughly dried, fills it with heavy spar, powdered in any *non*-metallic mortar. The bone is now closed with a clay lute, and inclosed in an iron tube, which is surrounded with fine clay, and the whole exposed for three hours to a red heat in a furnace. The substance which produces the effect is a sulphuret of barium. In the same manner strontian phosphorus is obtained from cœlestin.

Canton's phosphorus is prepared by exposing a mixture of three parts of sifted and calcined oyster-shells and one part of flowers of sulphur to a strong

fire for one hour. There are also many other phosphori; amongst these may be enumerated Osann's phosphori, Wach's phosphori, Homberg's phosphorus, Baldwin's phosphorus, and many kinds of fluor spar.

The phosphorescence of these various bodies, unlike that of the curious element phosphorus, is produced independently of any chemical change; and if inclosed in sealed glass tubes, and excluded from light, they may retain the property of showing phosphorescence for many years, whilst the light emitted from phosphorus is due to the slow oxidation of this element; and if this is arrested, by placing it in water, or in any gas, like nitrogen, the light is no



FIG. 7.—*The Phosphorescent Tubes.*

longer produced. Upon what principle, then, is it possible to explain the cause of the emission of light after exposing phosphori to the sun or any brilliant artificial light?

The most rational theory which can be suggested is, that the undulations of light convey their own vibratory motions to the phosphori, just as one musical instrument may cause another to vibrate symphathetically with it, and phosphorescence is observed so long as the substance continues to vibrate. In a dark room, and without a constant accession or supply of vibratory power, the light becomes fainter and fainter, until it is no longer capable of affecting the eye; the vibratory power, like any other mechanical motion, must come to an end when cut off from its source of power, when, as in this case, it is removed from the greater vibratory power, the sun or the burning magnesium, which originally set it in motion. This opinion is further confirmed when we take into account the large number of substances which may become phosphorescent in a tolerably high degree. If this property was confined to a few bodies, the theory might not be so applicable; but if it is agreed beforehand

that any particles may become luminous if they are capable of entering into that state of vibration which we suppose belongs to the sun and artificial sources of light, then it can be understood why the following organic or inorganic substances are all considered to enjoy in a limited degree the property of phosphorescence after exposure to the sun:—crystallized boracic acid, sal ammoniac, sulphate of potash, nitre, crystallized carbonate, borate, or sulphate of soda, rock salt, witherite, radiating heavy spar from Bologna, marienglas, fibrous gypsum, alabaster, artificial sulphate of lime, common fluor spar, crystallized sulphate of magnesia, crystallized alum, arsenious acid, pharmacolite, freshly prepared flowers of zinc, sulphate of mercury, tartar, benzoic acid, loaf sugar, sugar of milk, bleached wax, white paper (especially when it has been heated almost to burning), yellow and red paper, which are nearly as phosphorescent as white paper, egg-shells, corals, snails, pearls, bones, teeth, ivory, leather, and skins of men and animals, tartaric acid, also seeds, grain, flour, starch, crumbs of bread, gum arabic, feathers, cheese, yolk of egg, muscular flesh, tendons, isinglass, glue, horn,—all well dried; moreover, the albumen of trees, bleached linen, bleached cotton yarn, and other bleached vegetable fibres. The above is only a small instalment of the different chemical bodies and common substances which Gmelin enumerates when he speaks of those things which become phosphorescent by irradiation. Phosphorescence may also be further developed by heat, mechanical force, and crystallization, all of which are modes of motion, and suggest the setting up of a vibratory effect, resulting in the production of light. Chemical action, another mode of motion, is concerned in the phosphorescence of live animals and putrifying animal matter, and also in the production of the same effect in living and decaying plants.

HEAT A SOURCE OF LIGHT.

When iron is heated to a temperature of 635° Fahrenheit, it emits a dull red light, visible only in a darkened room. If the heat is further increased to 903° Fahrenheit, a bright red light is apparent, visible in a chamber fairly illuminated. The light attains a greater intensity at the moment the iron is heated to 1000° Fahrenheit. Thus, by the progressive increase of the heat of the iron, what is called a dull red, a pale red, and a white heat is obtained. By increasing the heat of a solid body a development of light or incandescence is obtainable.

LIGHT THE FREQUENT ATTENDANT OF ELECTRICAL PHENOMENA.

The intense and dazzling brightness of lightning has been known to cause temporary and permanent blindness. The immense electric spark, the result of the discharge of thousands of acres of charged clouds, will probably be more closely imitated than ever by an enormous induction coil, now being constructed by Mr. Apps for the Royal Polytechnic, which is calculated to give a spark 5 ft. in length, the usual length being from 5 to 18 in., or, in very rare cases, 2 ft. At the moment of discharge the electricity may develop light, heat, magnetical, mechanical, and chemical effects. Here is a correlation of forces that might well excuse Oersted in proposing a theory of light in which he regards light as the result of electric sparks.

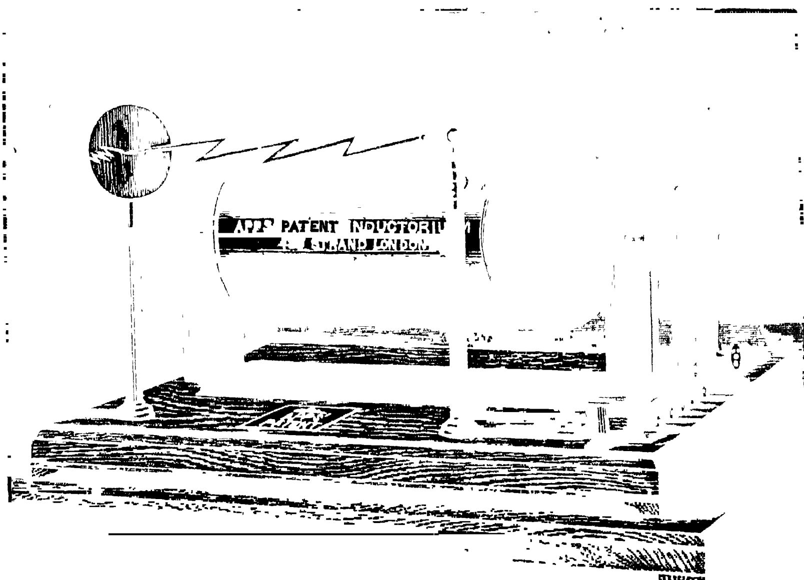


FIG. 8.—*The Inductorium of Mr. Apps, giving sparks* 18 *in. in length.*

CHEMICAL COMBINATION A SOURCE OF LIGHT.

Finely divided lead or iron shaken from a tube into the air or oxygen oxidizes rapidly, burns, and emits light. Finely powdered antimony unites rapidly with chlorine gas, and glows with the intensity of light whilst the

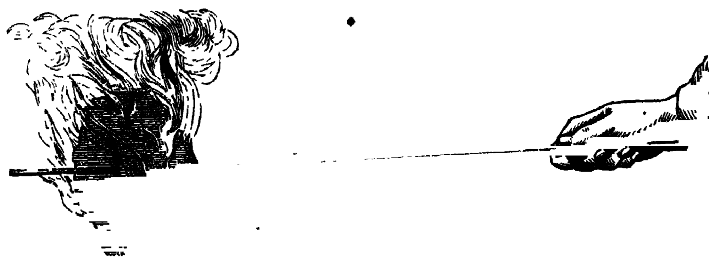


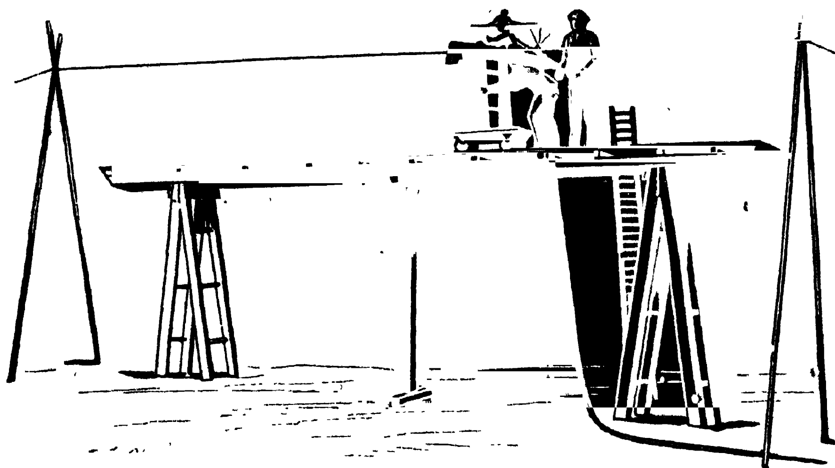
FIG. 9.—*Blotting-paper upon which the Solution of Phosphorus in Sulphide of Carbon has been poured, and then supported on an iron wire.*

combination is taking place. A solution of phosphorus in sulphide of carbon, poured upon blotting-paper, soon begins to evolve smoke, produced during the formation of phosphoric acid, and then rapidly and spontaneously catches fire

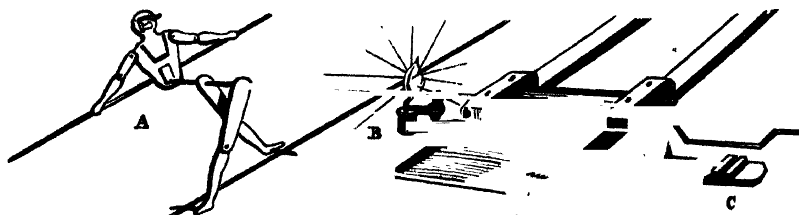
by the union of the finely divided phosphorus with the oxygen of the air. The name of Greek—modernized into Fenian—fire is given to this solution, which should only be made and used in small quantities.

IS MECHANICAL FORCE TO BE REGARDED AS A TRUE SOURCE OF LIGHT?

Since the numerous experiments made at Shoeburyness with iron plates and heavy guns, it has been ascertained over and over again that heat and frequently light are produced at the moment the impact or blow is given by the shot. The mechanical force, in the abstract, may be regarded as the source of light; but not perhaps directly, as the blow develops heat, and the latter,



FIGS. 10 and 11.—*The Shadow Blondin.*



Arrangement of Mechanism and Oxy-Hydrogen Light required to produce the effect of the Shadow Blondin. A, the mechanical figure; B, the lime-light; C, the handles used to produce the movements of the figure.

probably, the light. It is found that almost all bodies which acquire phosphorescence by exposure to the sun, or insolation, or by heat, also become luminous by friction or percussion. Sometimes the light obtained by friction is simply electrical. The sparks from a flint and steel are due to the combustion of minute particles of metal accelerated by the heat eliminated at the

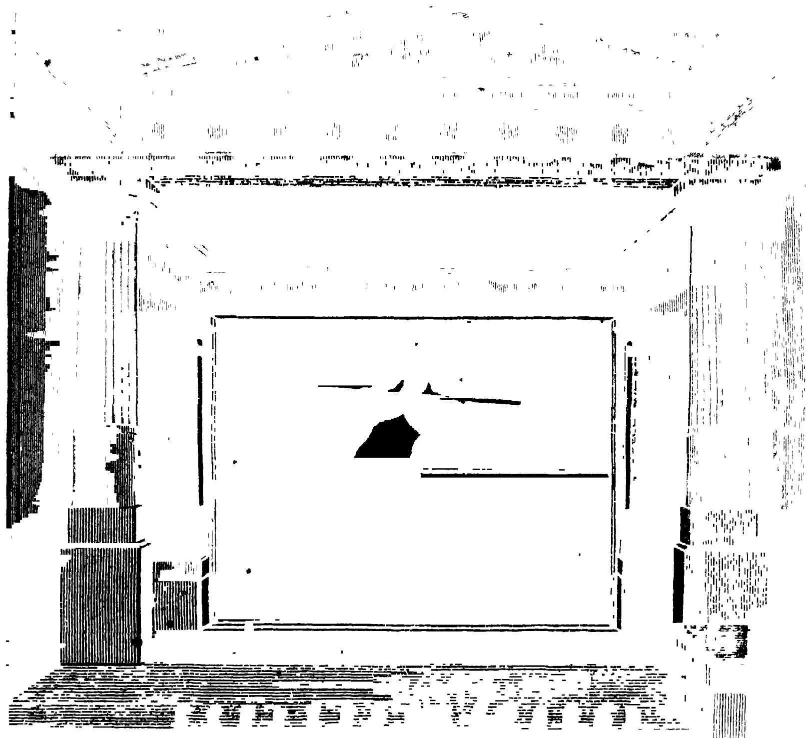


FIG. 12.—*Effect in front of the Curtain.*

moment the particle is struck off. Mechanical force can only be regarded as an indirect mode of producing light, because heat is first developed; heat is a source of light.

From what has been previously stated, it will be understood that all matter may be divided in relation to light into luminous and non-luminous bodies. The sun or a lighted lamp would represent the former, and the moon with the other planets, or a piece of whitened board, the latter, because our satellite shines by borrowed light from the sun, and not by any inherent self-luminosity; the piece of board will reflect and scatter the rays of light from the lamp, and whilst doing this appears very bright. At the same time the board obstructs the light and casts a shadow behind it, and thus indicates another relation of light to solid matter, called opacity; the opposite to this property being transparency, whilst the intermediate links between opacity and transparency are termed semi-transparency, or opalescence. There are many very amusing effects produced by casting shadows of living or inanimate objects on a transparent disc by the oxy-hydrogen light. (Figs. 10, 11, 12.)

The shadow pantomimic action of living figures visible on a transparent disc with this strong light, and first introduced by the author at the Polytechnic, has gone the round of nearly all the exhibitions and theatres in London and New York.

There still remains, however, something new and amusing even in this hackneyed branch of light. Mr. Walker, jun., constructed a very simple and ingenious piece of mechanism, and giving it the outline of a human figure, produced a good imitation of the bold feats performed by Monsieur Blondin on the high rope. The shadow of the figure only was projected on to the disc by the lime-light, and it simulated all the usual movements, such as standing, walking, dancing, and sitting astride the rope. Indeed it did rather more than the living prototype, for the figure stood on its head, and threw the most unnatural but highly-amusing sommersaults. (Figs. 10, 11, 12, pp. 12, 13.)

THE DIFFUSION OF LIGHT.

A luminous object evolves light from every visible point of its surface, and if a single point of light were placed in the centre of a hollow globe, every portion of the internal area would be equally illuminated.

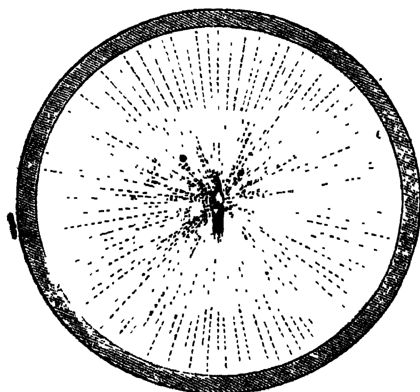
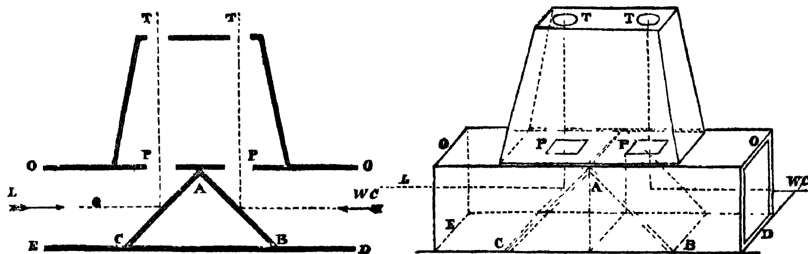


FIG. 13.—*A Flame in the centre of a circle, throwing out rays in every direction, like the spokes of a wheel.*

Owing to the manner in which light is distributed and transmitted in straight lines diverging from each other, its intensity diminishes as the square of its distance from the luminous source increases, and it is on this principle that the instruments called photometers, or light-measurers, are constructed.

A scale of 20 ft. in length, divided into feet and inches, may be used in conjunction with a box somewhat like a stereoscope, containing two mirrors placed at an angle of 45°, and reflecting the rays from the two sources of light which are to be confronted with each other. A candle, one of six to the

pound, and burning so many grains per minute, is fixed in a nozzle, which slides on the scale. The box, which may also slide or be fixed in the centre of the scale, reflects on one side the light from the lamp or gas-burner which is being tested, on the other it reflects the light of the candle. The experiment may be conducted either by placing the lamp and the candle at opposite ends of the scale, and moving the box with the reflectors until the two spots of light are equal; or, the box being fixed in the centre, and the lamp under examination placed at one end of the scale, the candle may be moved towards the box till the lights are equal, the respective distances from the box being then squared, and the greater number divided by the less, will give the quotient which represents the illuminating power of the lamp as compared with the candle.



FIGS. 14 and 15.—*Ritchie's Photometer.*

Section of the box containing the mirrors A B, A C, openings D O, E O, to admit the light which is reflected from the mirrors on to two circular apertures P P, covered with oiled paper, which are seen and compared when looked at from the top at T T. The arrows indicate the direction of the rays from the lamp, and L, the wax candle W C. Example: the distance of the lights from the box being respectively 12 ft. and 3 ft. — 12 × 12 = 144 ÷ 3 × 3 = 9. Quotient, 16.

In the practice of photometry the standard used is a candle defined by Act of Parliament "as a sperm candle of six to the pound, burning at the rate of 120 grains per hour." This standard would be a very simple one if every candle could be made alike, but it unfortunately happens that the composition and the wick are not always the same, and as important experiments have to be made in various parts of the United Kingdom, it becomes difficult to assimilate and compare them with each other. All authorities on this question have condemned the use of test candles. The credit is due to Mr. Crookes, the editor of the "Chemical News," of devising a standard test lamp-wick and combustible fluid which could be made in every part of the civilized world, and of inventing an improved photometer, in which the phenomena of polarized light are employed. The following is the inventor's description of the apparatus and materials used, commencing with the lamp and its fuel:*

"Alcohol of sp. gr. 0.805, and pure benzol boiling at 81° C., are mixed together in the proportion of 5 volumes of the former and 1 of the latter. This burning fluid can be accurately imitated from description at any future time and in any country, and if a lamp could be devised equally simple and invariable, the light which it would yield would, it is presumed, be invariable. This difficulty the writer has attempted to overcome in the following manner.

* "Chemical News," July 17th, 1868.

"A glass lamp is taken of about 2 ounces capacity, the aperture in the neck being 0·25 inch diameter; another aperture at the side allows the liquid fuel to be introduced, and, by a well-known laboratory device, the level of the fluid in the lamp can be kept uniform. The wick-holder consists of a platinum tube 1·81 in. long, and 0·125 in. internal diameter. The bottom of this is closed with a flat plug of platinum, apertures being left in the sides to allow free access of spirit. A small platinum cup 0.5 in. diameter and 1 in. deep is soldered round the outside of the tube 0·5 in. from the top, answering the threefold purpose of keeping the wick-holder at a proper height in the lamp, preventing evaporation of the liquid, and keeping out dust. The wick consists of 52 pieces of hard-drawn platinum wire, each 0·01 in. diameter and 2 in. long, perfectly straight, and tightly pushed down into the platinum-holder until only 0·1 in. projects above the tube. The height of the burning fluid in the lamp must be sufficient to cover the bottom of the wick-holder; it answers best to keep it always at the uniform distance of 1·75 in. from the top of the platinum wick; a slight variation of level, however, has not been found to influence the light to an extent appreciable by our present means of photometry. The lamp having the reservoir of spirit thus arranged, the platinum wires parallel, and their projecting ends level, a light is applied, and the flame instantly appears, forming a perfectly shaped cone 1·25 in. in height, the point of maximum brilliancy being 0·56 in. from the top of the wick. The extremity of the flame is perfectly sharp, without any tendency to smoke; without flicker or movement of any kind; it burns, when protected from currents of air, at a uniform rate of 136 gr. of liquid per hour. The temperature should be about 60° F., although moderate variations on ither side exert no perceptible influence. Bearing in mind Dr. Franklin's observations on the direct increase in the light of a candle with the atmospheric pressure, accurate observations ought only to be taken at one height of the barometer To avoid the inconvenience and delay which this would occasion, a table of corrections should be constructed for each 0·1 variation of barometric pressure.

"There is no doubt that this flame is very much more uniform than that of the sperm candle sold for photometric purposes. Tested against a candle, considerable variations in relative illuminating power have been observed; but on placing two of these lamps in opposition, no such variations have been detected. The same candle has been used, and the experiments have been repeated at wide intervals, using all usual precautions to ensure uniformity." The results are thus shown to be due to variations in the candle, and not in the lamp.

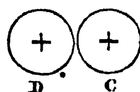
In Arago's "Astronomy," the author describes his photometer in the following words:

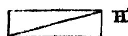
"I have constructed an apparatus by means of which, upon operating with the polarized image of a star, we can succeed in attenuating its intensity by degrees exactly calculable after a law which I have demonstrated.'" It is difficult to obtain an exact idea of this instrument from the description given; but from the drawings it would appear to be exceedingly complicated, and to be different in principle and construction from the one now about to be described. The present photometer has this in common with that of Arago, as well as with those described in 1853 by Bernard,* and in 1854 by Babinet,†

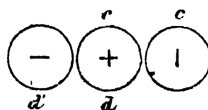
* "Comptes Rendus," April 25, 1853.
† "Proceedings of the British Association," Liverpool Meeting, 1854

that the phenomena of polarized light are used for effecting the desired end. But it is believed that the present arrangement is quite new, and it certainly appears to answer the purpose in a way which leaves little to be desired. The instrument will be better understood if the principles on which it is based are first described.

"Fig. 16 shows a plan of the arrangement of parts, not drawn to scale, and only to be regarded as an outline sketch to assist in the comprehension of general principles. Let D represent a source of light. This may be a white disc of porcelain or paper illuminated by any artificial or natural light. C represents a similar white disc likewise illuminated. It is required to compare the photometric intensities of D and C. (It is necessary that neither D nor C should contain any polarized light, but that the light coming from them, represented on each disc by the two lines at right angles to each other, forming a cross, should be entirely unpolarized.) Let H represent a double-refracting achromatic prism of Iceland spar; this will resolve the disc D into two discs, *d* and *d'*, polarized in opposite directions; the plane of *d* being, we will assume, vertical, and that of *d'* horizontal. The prism H will likewise give two images of the disc C; the image *c* being polarized horizontally, and *c'* vertically. The size of the discs D, C, and the separating power of the prism H are to be so arranged that the vertically polarized image *d*, and the horizontally polarized image *c*, exactly overlap each other, forming, as shown in the figure, one compound disc, *c d*, built up of half the light from D and half that from C.







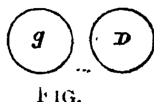


FIG.

"The measure of the amount of free polarization present in the disc *c d*, will give the relative photometric intensities of D and C.

"The letter I represents a diaphragm with a circular hole in the centre, just large enough to allow the compound disc *c d* to be seen, but cutting off from view the side discs *c' d'*. In front of the aperture in I is placed a piece of selenite of appropriate thickness for it to give a strongly-contrasting red and green image under the influence of polarized light. K is a doubly-refracting prism, similar in all respects to H, placed at such a distance from the aperture in I that the two discs into which I appears to be split up are separated from each other, as at *g* D. If the disc *c d* contains no polarized light, the images *g r* will be white, consisting of oppositely polarized rays of white light; but if there is a trace of polarized light in *c d*, the two discs *g r* will be coloured complementarily, the contrast between the green and red being stronger in proportion to the quantity of polarized light in *c d*.

"The action of this arrangement will be readily evident. Let it be supposed in the first place that the two sources of light, D and C, are exactly equal. They will each be divided by H into two discs, *d' d* and *c c'*, and the two polarized rays of which *c d* is compounded will also be absolutely equal in intensity, and will neutralize each other and form common light, no trace of free polarization being present. In this case the two discs of light *g* D will be colourless. Let it now be supposed that one source of light (D for instance)

is stronger than the other (C). It follows that the two images *d' d* will be more luminous than the two images *c c'*, and that the vertically polarized ray *d* will be stronger than the horizontally polarized ray *c*. The compound disc *c d* will therefore shine with partially polarized light, the amount of free polarization being in exact ratio with the photometric intensity of D over C.

"In this case the image of the selenite plate in front of the aperture I will be divided by K into a red and a green disc.

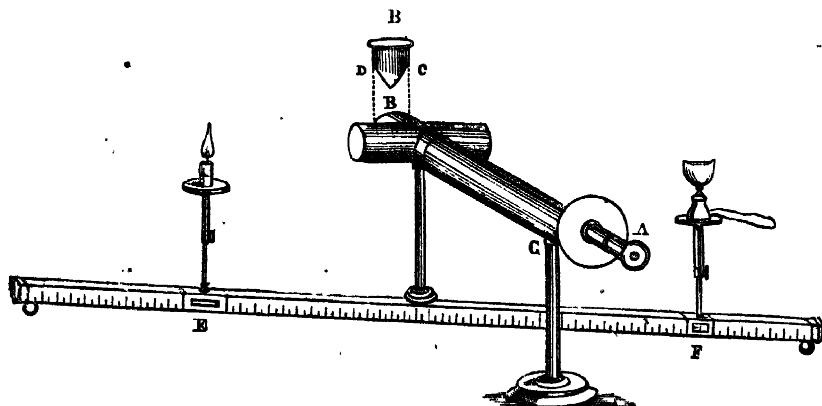


FIG. 17.

"Fig. 17 shows the instrument fitted up. A is the eye-piece (shown in enlarged section at Fig. 3). G B is a brass tube, blacked inside, having a piece, shown separate at D C, slipping into the end B. The sloping sides, D B, B C, are covered with a white reflecting surface (white paper or finely ground porcelain), so that when D C is pushed into the end B, one white surface, D B, may be illuminated (as in Fig. 17) by the candle, and the other surface, B C, by the lamp. If the eye-piece A is removed, the observer, looking down the tube G B, will see at the end a luminous white disc divided vertically into two parts, one half being illuminated by the candle E, and the other half by the lamp F. By moving the candle E, for instance, along the scale, the illumination of the half D B can be varied at will, the illumination of the other half remaining stationary.

"The eye-piece A (shown enlarged at Fig. 18) will be understood by reference to Fig. 16, the same letters representing similar parts. At L is a lens to collect the rays from B D C, Fig. 17), and throw the image into the proper part of the tube. At M is another lens, so adjusted as to give a sharp image of the two discs into which I is divided by the prism K. The part N is an adaptation of Arago's polarimeter; it consists of a series of thin plates of glass capable of moving round the axis of the tube, and furnished with a pointer and graduated arc. By means of this pile it is possible to partially polarize the rays coming from the illuminated discs in one or the other direction, and thus bring to the neutral state the partially polarized beam *c d* (Fig. 16), so as to get the images *g* D free from colour. It is so adjusted that when at the zero point it produces an equal effect on both discs.

"The action of the instrument is as follows. The standard lamp being placed on one of the supporting pillars which slide along the graduated stem (Fig. 17), it is adjusted to the proper height, and moved along the bar to a convenient distance, depending on the intensity of the light to be measured; the whole length being a little over 4 ft., each light can be placed at a distance of 24 in. from the disc. The flame is then sheltered from currents of air by black screens placed round, and the light to be compared is fixed in a similar way on the other side of the instrument. The whole should be placed in a dark room, or surrounded with non-reflecting screens; and the eye must also be protected from direct rays from the two lights. On looking through the eye-piece two bright discs will be seen, probably of different colours. Supposing E represents the standard flame, and F the light to be compared with it, the latter must now be slid along the scale until the two discs of light, seen through the eye-piece, are about equal in tint. Equality of illumination is easily obtained; for, as the eye is observing two adjacent discs of light, which pass rapidly from *red-green* to *green-red*, through a neutral point of no colour, there is no difficulty in hitting this point with great precision. It has been found most convenient not to attempt to get absolute equality in this manner, but to move the flame to the nearest inch on one side or the other of equality. The final adjustment is now effected at the eye-end, by turning the polarimeter one way or the other up to 45°, until the images are seen without any trace of colour. This will be found more accurate than the plan of relying entirely on the alteration of the distance of the flame along the scale; and, by a series of experimental adjustments, the value of every angle through which the bundle of plates is rotated can be ascertained once for all, when the future calculations will present no difficulty. Squaring the number of inches between the flames and the centre will give their approximate ratios; and the number of degrees the eye-piece rotates will give the number to be added or subtracted in order to obtain the necessary accuracy.

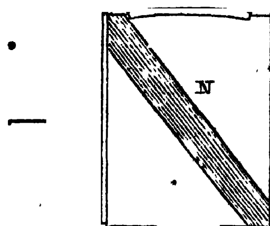


FIG. 18.

"The delicacy of the instrument is very great. With two lamps, each about 24 in. from the centre, it is easy to distinguish a movement of one of them to the extent of 1-10th of an inch to or fro; and by using the polarimeter, an accuracy considerably exceeding that can be attained.

The employment of a photometer of this kind enables us to compare lights of different colours with one another, and leads to the solution of a problem which, from the nature of their construction, would be beyond the powers of the instruments in general use. So long as the observer, by the eye alone, has to compare the relative intensities of two surfaces respectively

illuminated by the lights under trial, it is evident that unless they are of the same tint it is impossible to obtain that absolute equality of illumination in the instrument which is requisite for a comparison. By the unaided eye one cannot tell which is the brighter half of a paper disc illuminated on one side with a reddish, and on the other with a yellowish light; but, by using the above-described photometer, the problem becomes practicable. For instance, on reference to Fig. 16, suppose the disc D were illuminated with light of a reddish colour, and the disc C with greenish light, the polarized discs *d′ d* would be reddish, and the discs *c′ c* greenish, the central disc *c d* being of the tint formed by the union of the two shades. The analysing prism K, and the selenite disc I, will detect free polarization in the disc *c d*, if it be coloured, as readily as if it were white; the only difference being that the two discs of light *g r* cannot be brought to a uniform *white* colour when the lights from D and C are equal in intensity, but will assume a tint similar to that of *c d*. When the contrasts of colour between D and C are very strong—when, for instance, one is a bright green and the other scarlet—there is some difficulty in estimating the exact point of neutrality; but this only diminishes the accuracy of the comparison, and does not render it impossible, as it would be according to other systems.

"No attempt has been made in these experiments to ascertain the exact value of the standard spirit-flame in terms of the Parliamentary sperm candle. Difficulty was experienced in getting two lots of candles yielding light of equal intensities; and when their flames were compared between themselves and with the spirit-flame, variations of as much as 10 per cent. were sometimes observed in the light they gave. Two standard spirit-flames, on the other hand, seldom showed a variation of 1 per cent., and had they been more carefully made they would not have varied 0·1 per cent.

"This plan of photometry is capable of far more accuracy than the present instrument will give. It can scarcely be expected that the first instrument of the kind, roughly made by an amateur workman, should possess equal sensitiveness with one in which all the parts have been skilfully made with special adaptation to the end in view."

MODIFICATIONS THAT LIGHT MAY UNDERGO.

1. In the same medium of the same density rays of light undergo no change.
2. When rays of light pass out of one medium into another, or into one of a different density, they may undergo the following modifications:
3. The rays of light may rebound from the surface of a solid, fluid, or gaseous body, and are then said to be reflected, the rebounding being denominated Reflection.
4. A ray of light, after passing into a substance, may be bent from its natural course, or Refracted.
5. A ray of light may be split into two portions when it enters certain bodies, such as Iceland spar, and each portion of the light possesses distinct properties.
6. A ray of light may be so checked in its passage that a portion may be lost or absorbed.
7. A ray of light, by reflection, refraction, double refraction, and absorption, may acquire new properties, and become what is termed Polarized Light.

THE REFLECTION OF LIGHT.

Catoptrics is the name given to all effects produced by reflection. It is a word taken from the Greek κατοπτρικὸς, "belonging to a mirror," and whilst the laws which govern the reflection of light are remarkably simple, they give rise to a most interesting series of phenomena.

Premising that the *incident* rays are those which fall on the surface, and that those sent off are called *reflected* rays, it is soon ascertained—1st, that the incident and reflected rays always lie in the same plane, *i.e.*, if the incident ray falls in a perpendicular plane or direction, the reflected one will also be in the same plane or direction; and the like reasoning applies to the horizontal position. 2nd, the incident and reflected rays always form equal angles, or when light falls upon any surface, whether plane or curved, the angle of reflection is equal to the angle of incidence.

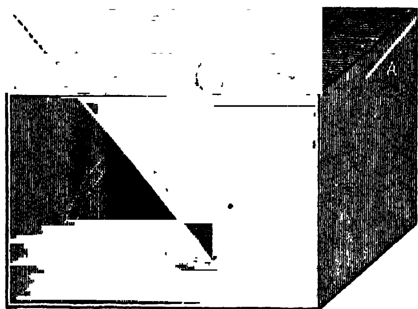


FIG. 19.
R R is the reflecting surface; A B is the incident ray; B C, the reflected ray; A B P, the angle of incidence; C B P, the angle of reflection.

The luminous rays may be *parallel* to each other, like the lines in a copy-book, or they may be *divergent* when they spread out in the same manner as the sticks of a fan, or *convergent* when they gradually approach each other, and end in a point like a spear-head.

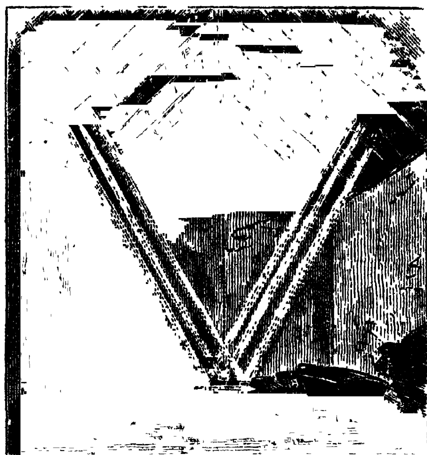


FIG. 20.—*Reflection of Parallel or Equi-distant Rays.*
R R R, the parallel rays incident on a plane or flat surface at T, and reflected in lines at equal distances from each other. The rays of the sun are nearly parallel with each other, and will illustrate this fact.

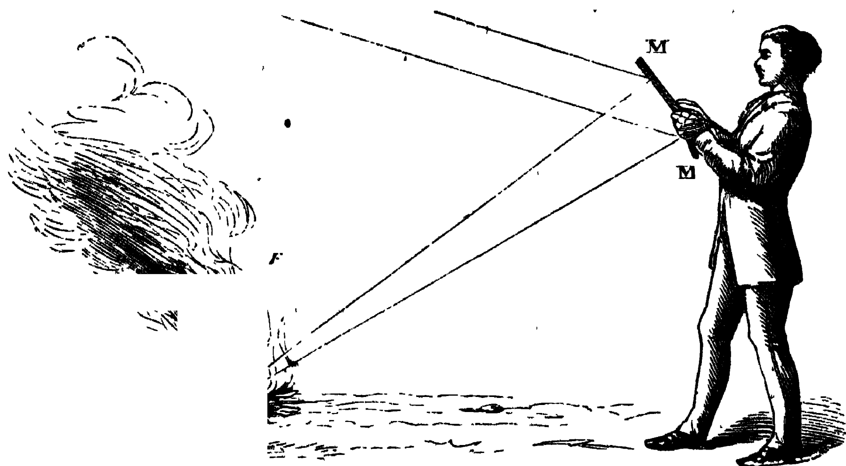


FIG. 21.

Parallel rays falling on a concave mirror, M M, converge or come to a focus or fireplace at F

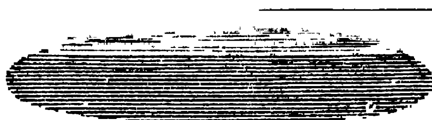


FIG. 22.

Reflection of parallel rays from a convex mirror. The rays which are reflected become divergent, and are shown on the ceiling.

A very large number of the waves of light are lost when they fall even upon the most perfectly polished metallic mirrors; thus light reflected from a clear and bright surface of metallic mercury at an angle of 78° 5′ loses nearly one quarter, and only 754 rays out of 1000 are reflected.

A transparent substance, like glass, reflects more light from the second surface than the first; and if the former is coated with an amalgam of tin and mercury, the brilliancy of the reflection of the second or coated surface overpowers that of the first, although if a candle is held opposite the best quicksilvered mirror two images are apparent.

In the production of illusory effects by reflection from the surface of glass, the image reflected from the surface of the first surface interferes with the second; but this may be prevented, as shown to the author by a friend, by coating the first side with a very delicate film of collodion or varnish, such as is used for photographic purposes. Thus the intensity of the reflection of the second surface is increased by a coating of amalgam, whilst the intensity of the reflection from the first surface is reduced by coating it with a substance like collodion, having an absorptive rather than a reflecting power on light. Where objects are reflected from either glass or silvered glass plane mirrors, they appear to come from the back, and the image is as far behind the glass as the real object is before it. It is this physical truth that increases so amazingly the effect of what is familiarly called "The Ghost Illusion." The spectator looking at the image does not observe the glass which has produced it, because the former is so far in advance of the latter. Had this physical fact in catoptics been remembered, many scientific men would have sooner discovered the secret of the illusion by looking in front of the image for the glass or reflecting surface.

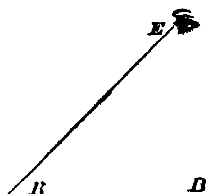


FIG. 23.

O, the real object reflected from the glass A B, at R, to the eye at E; S O, behind the glass, is where the image appears to come from, and if the whole distance from E to S O is measured, it will be found equal to E R, R O.

The same truth is still more apparent when divergent or convergent rays are traced out in their reflections from a plane surface of glass.

To cause the image or ghost to appear, the lights are alternately thrown on or cut off the real figure. (See Fig. 24, p. 24.)

This mode of showing the ghost has to be modified when the angles of vision are so different as seen from the pit, boxes, and gallery of a theatre. Then it is advisable to sink a stage a few feet below the regular stage, and to arrange a board at the same angle as the glass, on which the living figures recline. The latter method allows only certain movements to be exhibited, and is called the "spectroscope" and "phantoscope" by travelling showmen who exhibit the ghost.

One of the prettiest stories which can be illustrated with this illusion is that called "The Knight watching his Armour," and as many persons have

seen it at the Polytechnic, and doubtless might wish to entertain others with this popular illusion the little tale is added as a sequel to the contrivance itself.

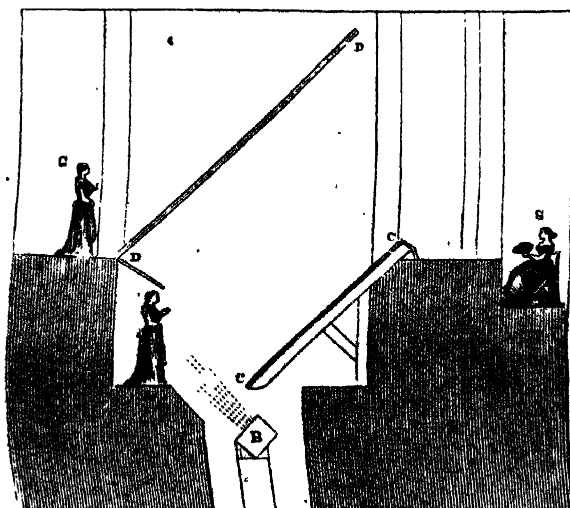


FIG. 24.—*Exhibition of the "Ghost" at the Polytechnic, being a section of the stage in the large Theatre.*

A, the real figure; B, lime-light; C C, looking-glass; D D, plate glass: G, the spectral image or ghost, which would appear much farther behind the glass D D; S, spectators.

KNIGHT WATCHING HIS ARMOUR.

N.B.—The spectral image described appears at all places marked with a star, *

The following is told of a knight, called Hubert de Burgh, who won his spurs on Flodden Field:—

King James was so pleased with his deeds of valour, that he promised to dub him knight on the following morning; but told him that he would have to go through the ancient ordeal of watching his armour throughout the previous night.

Sir Hubert started with helmet and corselet to the church. Before entering, he met his lady-love, fair Agnes, and telling her of his good fortune, begged that their wedding might take place on the first day he wore his golden spurs.

The maiden consented, and told him that she would also watch with him in spirit throughout the night, and bade him beware of the many temptations held out by the evil spirits to all warriors during the period of their watching.

After a loving farewell, Hubert commenced his duties. And now, for the first time, does he feel fatigue from his hard day's fighting; but remembering the caution that he must neither eat, drink, nor sleep during his vigils, he continues to watch and fast until the break of morn: sitting down, he thinks of his good fortune in winning the prize so much coveted by all true warriors. Whilst buried in thought he hears the sound of approaching footsteps, and



Fig. 25.

feels that the time has come when he needs all his energy to keep his armour pure from evil touch. On looking up he beholds a Benedictine monk * standing near, watching him most carefully.

"Peace be with you," says the monk.

"Amen, father," replies the knight.

"My son," continues the friar, "thou hast acted nobly this day, and deservest the honours our gracious sovereign is about to confer on thee; thou hast had a weary day, and needest rest and sustenance; sleep awhile, and I will keep custody over these true steel arms."

"Nay, father," said Hubert, "my duty is to watch, and not take deputy for this all-important work, neither will my instructions permit me to eat or sleep."

"My son," replies the priest, "as a brother of our holy order, I absolve thee

of this heavy charge, and will keep watch; and in that same capacity I bid thee drink. See! here is a cup of right good wine which will much relieve thee."

"Father," said Hubert, "sorry am I that mistrust enters my mind; I like not to break the solemn right, and though I would gladly accept thy proffered gift, I dare not, without you make the sign of your order over the wine."

The monk for some time hesitated, but at length in an angry tone replied—

"Fool! drink or starve; what care I for such a coward loon?"

"Now, by St. Peter," ejaculates Hubert, "these sound *not* like a good priest's words; thou wearest the dress without the sign of thy calling. Who art thou? Answer quickly, or this good sword shall make short work of thy disguised body."

Grasping his sword, he advances towards the friar, who, with a fiendish laugh, vanishes from before him, and is gone.

Hubert felt it must have been an evil spirit who sought to destroy him, and with firmer determination to resist, he again returns to his weary task. Some time elapsed, when there comes before him, gliding out of the darkness, a beauteous syren,* who speaks kindly and fairly to him of his great prowess and feats of arms. She tells him she is an inhabitant of fairy-land--in fact, their queen—that she loves him fondly, and beseeches him to come to their fairy home, where he shall reign supreme.

She pictures to him the delight of being always young and gay—of being master of countless hosts—flying through the night amidst the stars—prince of all the land; and in such strains does she pour forth her eloquence, that he flies with her in fancy through the realms she so beautifully describes; but the thought of his fair Agnes, and the promise made, recalls him to his duty, and slowly advancing towards his armour, he lays his hand on the left side of his corselet, saying, "If thou be a spirit of evil, thus do I destroy thy charm." The temptress gives one faint sigh, and vanishes from his view.

Hubert, now relieved from a second temptation, watches with renewed vigilance; he now knows that the morn is not far distant—that morn which blesses him doubly, by giving him the name of knight and a fair bride.

The thought of Agnes causes him pain: "So soon shall I be forced to leave her, to seek a fortune which I have not;" and for the first time he knew what it was to wish for wealth. Whilst deep in thought how he should increase his little store of treasure, a stately man, dressed in the garb of a wealthy merchant, stands before him and questions him upon the sadness of his looks.* "For one so young," said his visitor, "should ne'er be sad."

"Good sir," replies Hubert, "thou seemest kindly in thy manner, so will I tell thee of my only grief. To-morrow, by the will of our good king, I put on the golden spurs of knighthood, I wed a noble lady, whom I shall drag down to my own level of poverty; though the world has given me an honoured name, still do I lack the wealth to keep my wife in station that befits her, and calm reflection tells me I did wrong to take her promise, and so, sir, do I feel sad."

"Beshrew me, but thou art a noble youth," replies the merchant—"noble in thought as well as deed, and if it had been ordained that I was blessed with such a son, he should not long need wealth."

"Ah!" said Hubert, "fate has not given me a parent's love, care, or assistance; my mother died when I was yet a babe, and ere many months my father followed her, dying as a noble soldier should, upon the battle-field."

"Stay, said the merchant, "may I again question thee as to whether him

you spoke of was the noble Ralph de Burgh, one of my most true and honest friends?"

"'T is so," said Hubert, "and if my father sought to win your friendship, pray extend the same good fellowship to his son."

"That I will, right willingly," returns the merchant. "Stay," continued he, "methinks you said you needed gold—nay, turn not away—I have enough, too much for an old and childless man. Say, let me aid thee. I ask it as a favour; nay, I command it, as your father's friend. Here, take this purse to meet your most urgent wants, and to-morrow shalt thou revel in as great wealth as any son of our noble houses. Nay, I will take no denial."

Hubert, who had been struggling within himself as to his right to take the proffered gift, at last rises to approach the stranger, when he imagines he hears sweet music passing through the air. He stops to listen, and fancies he hears a well-known voice exclaim, "Beware! keep to your trust, 't is almost morn." Amazed, he steps back, and sees his fair Agnes beckoning him away,* and waving the merchant back, who, with a frown and disappointed look, fades into the darkness.

The maiden said, "Dear Hubert, thy task is finished; for see, the morn is breaking. Farewell; we meet again at noon, never to be parted. I said I would watch over thee in spirit; say, have I performed the task?"

As the warrior is about to embrace his beloved, she disappears from before him.

The first tint of the morning sun soon glistened upon his helmet; so this true knight had watched from eve till sunrise to guard his armour from all evil spirits.

IMAGES FORMED BY SILVERED MIRRORS.

Soon after the novelty of "the Ghost" had waned, another illusion was presented to the public called "Proteus; or, We are Here, but not Here," Mr. Thomas Tobin and the author being co-inventors. A large and handsome box, like a huge sentry-box on wheels, and raised from the floor so that the spectators could see under, over, and all round it, is wheeled on to the platform (Fig. 26). On being opened it appeared to be well lighted from the top by an ordinary railway carriage lamp, and, of course, seemed to be perfectly empty. The assistant being now invited to enter the box, the door is closed and locked, and, after a few minutes have elapsed, is re-opened, when a skeleton appeared to be standing in the very place where the living being had been formerly observed (Fig. 27.) Again the door is closed, and the next time it is opened the skeleton has vanished, and the assistant walks out of the box with a carpet bag. The person explaining the apparatus now goes in, and sounds the walls all round with his knuckles; and, while doing this, the door is suddenly closed, and being as quickly opened, he is found to have disappeared, again to appear after the door is once more closed and opened. This illusion is produced by two plane silvered mirrors, folding into the sides of the box, and when open forming together an angle of 45°. The mirrors when open reflect the two sides of the box, and, as already explained, they appear behind the mirrors, and cause the spectator to suppose that he is looking at an empty box. In the angle formed by the mirrors the skeleton is concealed and brought out when required, and in the same place the assistant and lecturer are alternately hidden. Thus a box can be constructed in which the most elaborate tricks of the Davenport Brothers may be performed.

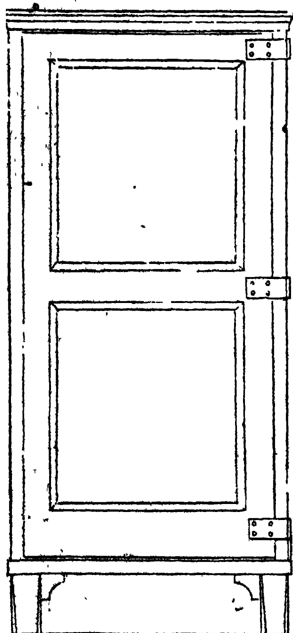


FIG. 26.

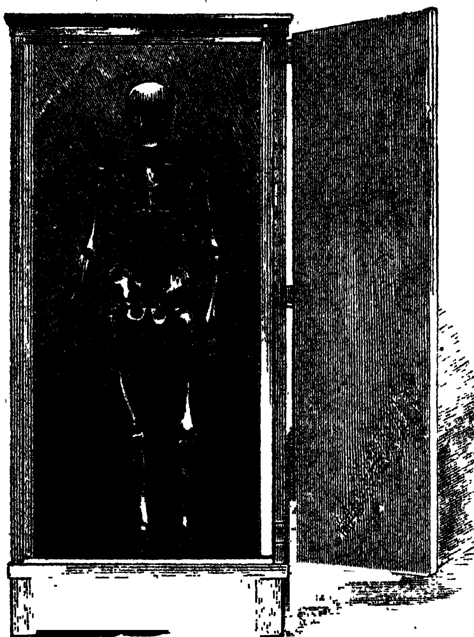


FIG. 27.

In the accompanying drawings, Fig. 26 is an exterior, and Fig. 27 an interior view, and Fig. 28 a horizontal section of the box or chamber above referred to. The sides may be made of wood, or papier maché, or sheet iron, but the former is preferred.

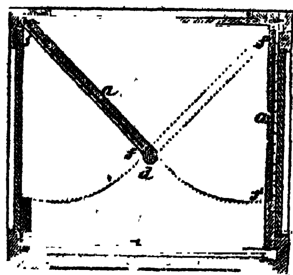


FIG. 28.

a a are two doors hung at the angles of the box, and capable of closing on the post *d* or of lying back in a recess in the sides, as shown on the right-hand side of the box. These doors *a a* have glass mirrors on the sides *f f f f*, and a fresco or design at the upper part of the box or chamber suitable for the illusion to be represented. The post *d* is set at the junction of the lines bisecting the angles of the back and sides. The box or chamber as shown is rectangular. If, for convenience or for the purpose of any particular representation, the box or chamber is desired to be wider at the front than at the back, the post will still be placed at the junction of the two lines bisecting the angles made by the back and two sides, but any considerable departure from the rectangular form would be found inconvenient. *b* is a door of clear thick plate glass; *c* is the external door. A lamp is hung at the top of the post *d* to light and assist in ventilating

the box by promoting an upward current, and a mat or rug is placed at the bottom of the box or chamber.

The same co-inventors, by placing a silvered-glass mirror at an angle, and thrown back from the spectators, produced some very popular illusions, one of which, called "The Modern Delphic Oracle," may be thus described. The curtain being raised, a person dressed in the garb of an ancient Athenian nobleman walks through and out of the entrance to a temple, across which a curtain rolls as he passes. Walking in front, he throws incense on a brazier of charcoal, and invokes Socrates to appear. The curtain now rolls back and

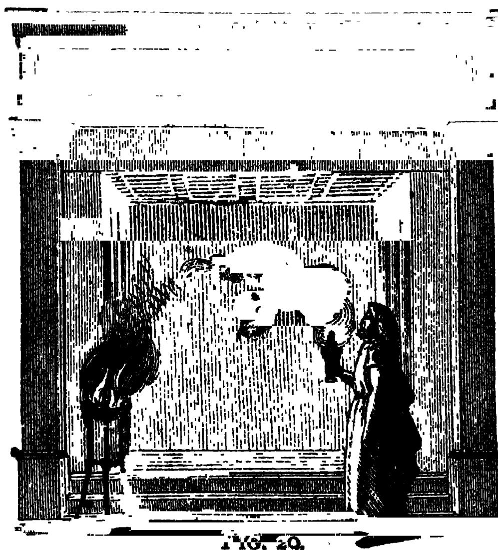


Fig. 29.

Elevation showing the appearance presented by the illusion called "The Modern Delphic Oracle."

discloses the head of the sage floating in the air, the proof of its solidity being that it casts a shadow on the wall behind. The Greek asks Socrates whether the words he spoke on the occasion of his memorable trial accurately expressed his real convictions—whether the purpose of his life was as pure as we have been taught to believe. The sage replies:

"It was my purpose ever to control
The stormy passions that perturb the soul;
Averse from idle pomp and wealth, to find
The only lasting treasure in the mind.
The truth I learned without reward to teach.
And show the falsehood hid by forms of speech;
The voice that warned within me to obey -
That safest guide—when doubtful was my way.
I learned to live as one prepared to die,
And calmly met my fate when death drew nigh;
Rejoiced to quit this troubled world, and rest
Immortal in the regions of the blest!" *

* Written by John Oxenford, Esq.

curtain once more rolls before the entrance, and as it is re-opened to allow the Athenian to pass through, the head has vanished, and nothing but the bare walls are apparent.

This illusion is performed with the aid of a large silvered mirror, which is placed at an angle across the small chamber in which the head appears, and being perforated in the centre, the head of the actor is thrust through the hole, whilst the rest of the large mirror conceals his body, and, reflecting only the top of the room, painted to represent the back of the temple, induces the spectator to suppose he is looking at a head suspended in an empty room.

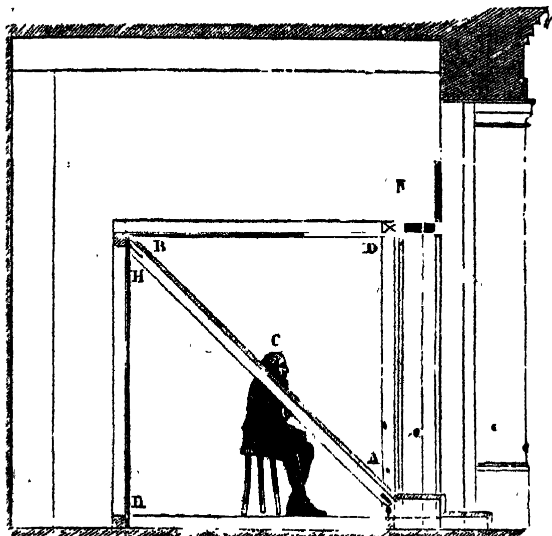


FIG. 30.

Transverse section · A B, the silvered mirror; C, the hole through which the actor thrusts his head; B D, the ceiling painted is reflected in the mirror, and appears behind the head at H H.

The mirror is carefully supported on a framework on wheels, and can be rolled out of the way when the actor representing the Athenian walks through in coming out and returning to the temple.

The exhibition of the Ghost at the Polytechnic took London by surprise as a novelty. It is, however, evident from the next diagram, copied from "Robinson's Recreative Memoirs," published in 1831, that he approached very near to the arrangements necessary to produce reflected images from plane surfaces. In the first place, Robertson remarks, it is necessaay to take care that the angles of the mirror must not exceed 20°. You may try in vain to increase this angle by increasing the size of the mirrors *a*, *b*, *c*, which reciprocally cause the rays to pass through the opening where a double-convex lens is placed. Thus to obtain an image of the same size as the object—say 6 ft. high—it is necessary to place the figure 18 ft. distant from the mirror *c*, and to use a lens of 9 ft. focus, to have the image 18 ft. on the other side of

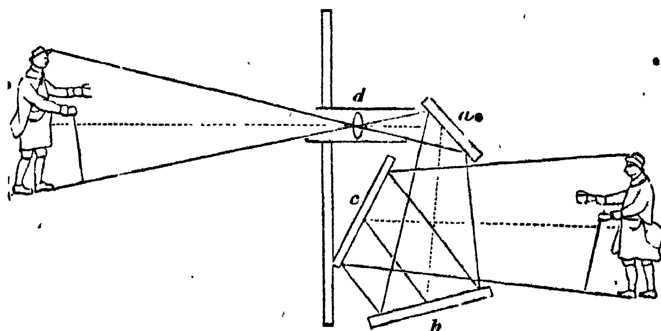


FIG. 31.—*Robertson's proposed Apparatus for Ghost.*

the partition, where it is projected on to the curtain or screen. You may place the real figure on the lens side or the mirror side. Robertson then gives directions for altering the positions of the figures, according to the space the operator has on either side of the partition. It is, however, difficult to conceive that the image thrown upon a screen in this way could have been properly illuminated, unless sunlight was employed. The whole diagram betrays theory instead of practice.

THE KALEIDOSCOPE.

One of the most philosophical and beautiful instruments ever constructed, and, like the above illusion, wholly dependent on reflection, is the amusing toy invented by the late Sir David Brewster, called the Kaleidoscope, from the Greek words καλὸς, beautiful, ειδος, a form, and σκοπέω, to see. Sir David Brewster says, "The first idea of this instrument presented itself to me in the year 1814, in the course of a series of experiments on the polarization of light by successive reflections between plates of glass, which were published in the 'Philosophical Transactions' for 1815, and which the Royal Society did me the honour to distinguish by the adjudication of the Copley medal." "On the 7th February, 1815, when I discovered the development of the complementary colours by the successive reflection of polarized light between two plates of gold and silver, the effects of the kaleidoscope, though rudely exhibited, were again forced upon my notice. In repeating, at a subsequent period, the very beautiful experiments of M. Biot on the action of homogeneous fluids upon polarized light, and in extending them to other fluids which he had not tried, I found it most convenient to place them in a triangular trough, formed by two plates of glass cemented together by two of their sides, so as to form an acute angle. The ends being closed up with pieces of plate glass cemented to the other plates, the trough is fixed horizontally for the reception of the fluids. The eye being necessarily placed without the trough, and at one end, some of the cement, which had been pressed through between the plates at the object end of the trough, appeared to be arranged in a manner far more symmetrical and regular than I had before observed, when the objects, in my early experiments, were situated at a distance from the reflectors. From the

approximation to perfect symmetry which the figure now displayed, compared with the great deviation from symmetry which I had formerly observed, it was obvious that the progression from the one effect to the other must take place during the passage of the object from the one point to the other, and it became highly probable that a position would be found where the symmetry was mathematically perfect.

"By investigating this subject optically, I discovered the leading principles of the kaleidoscope in so far as the inclination of the reflectors, the position of the object, and the position of the eye are concerned.

"I found that in order to produce perfectly beautiful and symmetrical forms three conditions were necessary:

"Firstly, That the reflectors should be placed at an angle which was an even or an odd aliquot part of a circle when the object was regular and similarly situated with respect to both the mirrors; or an even aliquot part of a circle when the object was irregular and had any position whatever.

"Secondly, That out of an infinite number of positions for the object, both within and without the reflectors, there was *only one* where perfect symmetry could be obtained, namely, when the object was placed in contact with the ends of the reflectors. This was precisely the position of the cement in the preceding experiment with the triangular trough.

"Thirdly, That out of an infinite number of positions for the eye there was *only one* where the symmetry was perfect, namely, as near as possible to the angular point, so that the circular field could be distinctly seen.

"The great step, however, towards the completion of the instrument remained yet to be made, and it was not till some time afterwards that the idea occurred to me *of giving motion to objects, such as pieces of coloured glass, &c., which were either fixed or placed loosely in a cell at the end of the instrument.*

"When this idea was carried into execution, and the reflectors placed in the tube and filled up on the preceding principle, the kaleidoscope in its *simple form* was completed.

"When the kaleidoscope was brought to this degree of perfection, it was impossible not to perceive that it would prove of the highest service in all the ornamental arts, and would at the same time become a popular instrument for the purposes of rational amusement. With these views, I thought it advisable to secure the exclusive property of it by a patent. But, in consequence of one of the patent instruments having been exhibited to some of the London opticians, the remarkable properties of the kaleidoscope became known before any number of them could be prepared for sale.

"According to the computation of those who were best able to form an opinion on the subject, no fewer than 200,000 instruments were sold in London and Paris during three months.

"In order to construct the kaleidoscope in its most simple form, we must procure two reflectors about 5, 6, 7, or 8 in. long. These reflectors may be either rectangular plates, or plates shaped like those in Fig. 32, having their broadest ends, A O, B O, from 1 to 2 in. wide, and their narrowest ends, *a* E, *b* E, half an inch wide.

"If the reflectors are of glass, the newest plate glass should be used. The plate glass may be either quicksilvered or not, and its posterior surface may be ground, or covered with black wax, or black varnish, or anything else that reverses its reflecting power.

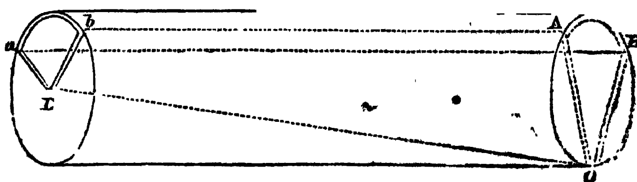


FIG. 32.

"The proper application of the objects at the end of the reflectors is now the only step which is required to complete the simple kaleidoscope. The most simple method consists in bringing the tube about half an inch beyond the ends of the reflectors. A circular piece of thin glass of the same diameter as the tube is then pushed into the tube so as to touch the reflectors. The pieces of coloured glass being laid upon this piece of glass when the tube is

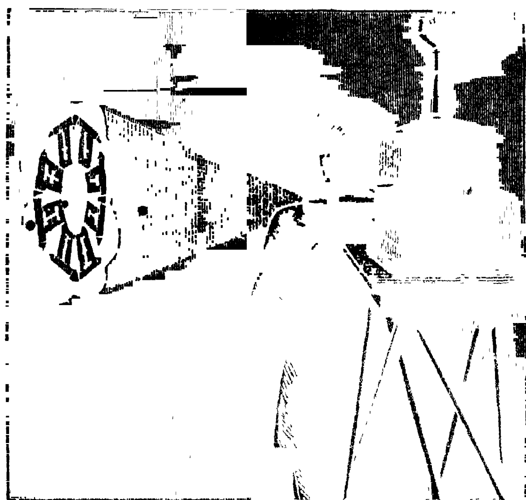


FIG. 33.—*The Oxy-hydrogen Kaleidoscope as made by Mr. Darker.*
Key pattern, produced from a key.

held in a vertical position, another disc, having its outer surface ground with fine emery, is next placed above the glass fragments, being prevented from pressing upon them by a ring of brass, and is kept in its place by burnishing down the end of the tube." Such, are the instructions given by Sir David Brewster for the manufacture of the ordinary kaleidoscope; he also speaks of the application of the instrument to the magic lantern, but as the details were not sufficiently complete to enable any one to throw the kaleidoscopic figure

on the disc, the author was induced to urge Mr. Darker, of Paradise Street, Lambeth, to persevere in the adjustment of the mirrors, lenses, and lighting until perfection was obtained. During the Christmas of 1866 the oxy-hydrogen kaleidoscope was exhibited daily at the Polytechnic with the greatest success, and by its means the principle of the instrument could be better understood.

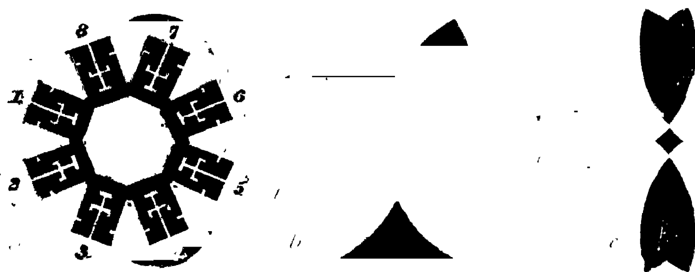


FIG. 34.
a, Figures obtained by putting a single figure, such as key, into the apparatus; *b*, *c*, other figures produced by using the light only with an empty slide.

It is chiefly by the adjustment of the light that the original angular opening is gradually multiplied by reflection eight times, and eight distinct sectors or divisions become visible on the disc. When the tip of the finger is now inserted, eight single reflections or four double ones are the result, and by thrusting in all the fingers the curious figures shown at *e*, Fig. 35, are obtained. Not only are transparent bodies, such as glass, exhibited with success, but any opaque object will produce the most distinct and symmetrical figures on the

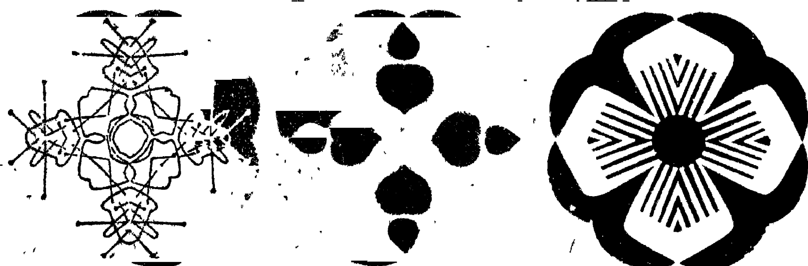


FIG. 35.
Figures obtained on the screen from the oxy-hydrogen kaleidoscope with pins and needles, D; the fingers, E; and F, a comb.

screen; in Fig. 35 the pattern *d* is chiefly produced with a cell containing only pins and needles. If glass be used, it should always be broken from coloured glass rods with the hammer, in order to secure the conchoidal fracture, as the wedge-shaped figures give gradual tones of colour, which are very pleasing to the eye, and produce fair imitations of the colours and grouping of rubies, emeralds, and sapphires when projected on the screen.

A gentleman, who saw these and other patterns, and especially some obtained by using ferns and other natural objects, was so pleased that he stated it was his intention to have an oxy-hydrogen kaleidoscope fitted up in his calico-printing establishment, in order to assist the artist who designed the patterns; and he stated that, although they had long used the ordinary kaleidoscope for this purpose, the oxy-hydrogen one gave a much better notion of the effect required to be produced, and would enable the manufacturer to select and decide upon the best patterns for commercial purposes.

The phenomena of light produced by reflection, and the instruments which have been constructed to demonstrate these effects, are too numerous to be detailed here, so that two or three examples must suffice. The property of reflection is affected more by the condition of the surface than by the physical nature of the substance used as a reflector. The kaleidoscope reflectors employed by Mr. Darker are made of the best plate glass, coated with metallic silver, and it is extremely difficult to prevent a slight deposit of moisture upon them. The watery particles greatly impair the kaleidoscopic figures, and demonstrate how thoroughly the power of reflection depends on the state of the surface, as this exquisitely thin film of moisture interferes with the perfect illumination of the kaleidoscopic figure.

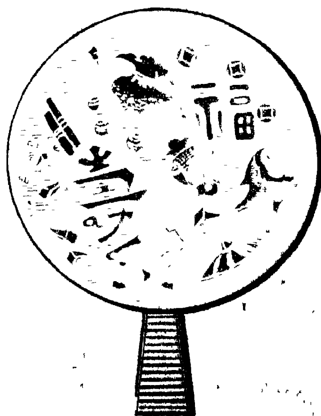


FIG. 36.—*Back of the Japanese Mirror.*

THE JAPANESE MAGIC MIRROR.

Some mirrors made in Japan have a very curious property. The back is usually ornamented with Japanese characters, also with flowers, vases, &c.; the front is polished in the usual manner, like any other metallic speculum, and, if carefully examined, with or without a magnifying power, betrays nothing more than the highly polished surface of the alloy, which appears to be composed chiefly of tin and copper. When, however, the mirror is held in the highly divergent rays emitted from an oxy-hydrogen light, it not only reflects on to a disc the surface of the polished disc, but likewise all the Japanese characters, vases, and flowers, which are *in relievo* on the back of the mirror.

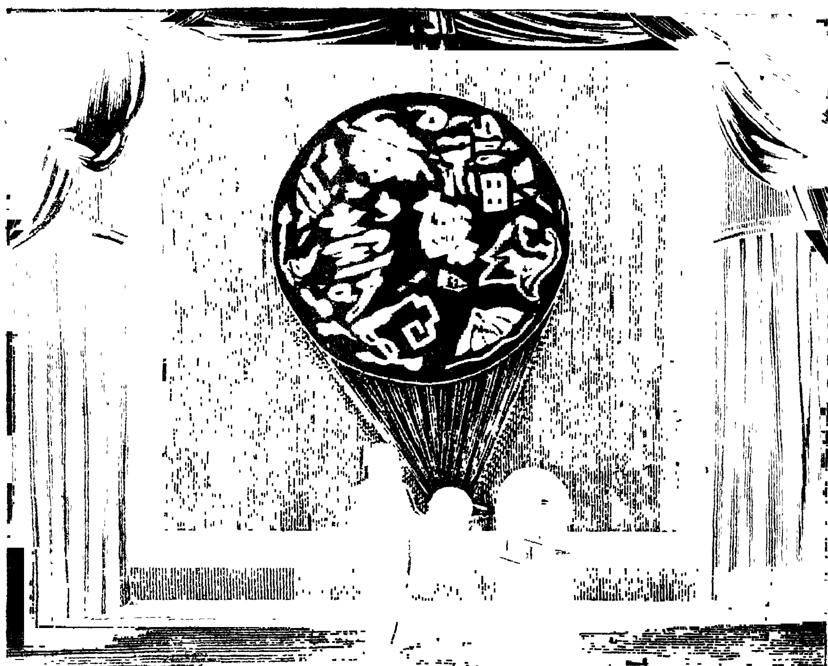


FIG. 37.—*Reflection from the front or bright side of the Japanese Mirror.*

We have in the above experiment a scientific puzzle that is somewhat difficult to explain. May it be supposed that much of the success of the effect obtained is due to the nature of the alloy used in the casting of the mirror? The figures in relief on the back of the mirror, during the operation of casting, must first enter the mould in the liquid state: are these first and quickly congealed before the whole mass of metal? and does the minute difference in the molecular condition of the metal produced by a greater rapidity of cooling, extend through the thin metal to the front and polished side?

Would careful heating and annealing destroy the effect? Whatever may be the method employed, it is certain that the figures reflected from the surface are wholly invisible, and cannot be observed in the strongest light and with a good magnifying-glass. In all cases where metals are inlaid with other metals the lines where the metals join are distinctly visible, and therefore it cannot be supposed that the Japanese mirror is made in this manner. Are the mirrors cast in a double mould, one side of which is in *intaglio* and the other in *relievo*, and after being cast do they grind down the sides of the mirror in which the figures are sunk, until they get a plain surface, which is then polished, leaving the other side and back of the mirror with the figures in relief? The pattern die, conferred on both sides of the metal whilst soli-

difying, might still further determine the molecular difference. It is a curious circumstance that the Chinese mirrors, made in imitation of the Japanese mirrors, do not answer the purpose, the former being much heavier than the latter. Whatever may be the secret of success, it is certain that this is only another instance of the remarkable ingenuity of the Japanese workers in metal.

Sir D. Brewster explains the apparent anomaly by suggesting that the design on the back is dexterously reproduced by careful engraving, which is so lightly done that the figures traced are quite invisible after the mirror is brought to the highest degree of polish, and it is only by submitting the mirror to a powerful light, and casting the reflection of the surface on a wall, that the design becomes apparent. The concealment of the most delicate engraving, unless done in some way by Barton's ruling-machine, would be extremely difficult, if not impossible. The Japanese know nothing of the machine with which Barton ruled his steel patterns, and even if they did the reflected patterns would give evidence of colour, which is not the case.

In the "Journal of the Asiatic Society," vol. i., page 242, there is a very clever paper, by James Prinseps, on "The Magic Mirrors of Japan." He says:

"The Japanese mirror is a slightly convex disc of bell metal, about 6 in. in diameter, and a quarter of an inch in thickness on the edge, ground and polished on the convex face, and covered with a thin coating of silver to give it a white colour. (Fig. 38, p. 39.)

"The back of the mirror is deeply curved or indented, with ornamental work in circles and festoons, and it bears an inscription in the Japanese character in high relief upon what may be termed the tympanum of the disc; in the centre there is a projecting knob, perforated laterally to receive a string for suspending the mirror. The metal is highly sonorous when struck as a bell, and is so soft as easily to be indented or scratched on contact with any hard substance. I found its composition to be

Copper	80
Tin	20
	100

with no traces of silver or arsenic, and a very slight indication of zinc."

Mr. Prinseps then describes the curious property of the mirror, similar in effect to those already mentioned and illustrated at Fig. 37, p. 36. He then proceeds to discuss the cause of this seeming anomaly.

"It then occurred that the various parts of the Japanese mirror might be of different *density*, supposing the pattern to be made by stamping, and that either the rays of light might be more forcibly repelled by the denser metal than by the lighter, or that parts of the surface would acquire different degrees of polish, sufficient to cause the illusion, although imperceptible to the eye. But in such case the thin parts, from being the hardest, should give the stronger reflection.

"This supposition was also overthrown by experiment. A disc of silver, having been annealed at a red heat so as to be quite soft, was stamped on the back with a circular ring, deeply indented, so as to harden the silver in that part only. The opposite surface was then ground and polished, when it was found to give a clear and uniformly reflected spectrum.

"Another and, I believe, the true explanation is suggested by the well-known

phenomenon of the reflection from a brass button, which every school-boy has remarked when sporting his Sunday 'blue coat with metal buttons' in the sunshine of his tutor's parlour-window. The button throws a radiated irregular image on the wall, exhibiting two bright concentric circles, one on the edge and another about one-third within it, and there is generally a bright spot in the centre: all of this seems but the picture of the stamp on the back of the button: the radii resemble, and indeed coincide with, the letters of 'superfine' or 'trebly gilt' inscribed within a double circle, and the central spot represents the shank. There can be little doubt that the principle is in this case precisely that of the Japanese mirror; and, on a cursory view, the surface looks equally smooth and unsuspicious. On minute examination, however, of several buttons, I found them to be by no means plane; their general surface is slightly convex; there is a hollow in the centre and a projection in the position of the inscription behind, caused no doubt by the blow necessary in stamping it. The polish is probably given by a rotary motion, and consequently does not remove these very small irregularities. To follow up the experimental investigation, I selected one of the buttons which gave a good image, ground it on a flat hone, and polished it: all of the magical figures vanished in a moment, and a plain, bright disc appeared in their stead. Here, then, may be a key to the mystery of the mirror: the deception is entirely produced by irregularities on the surface, which are rendered the less perceptible to the eye because the surface is convex instead of being plane. But it may be objected that the two circles which appear bright in the reflected spectrum of the button represent the indented or thin parts of the metal, whereas the thick parts of the Japanese mirror are those which will appear illuminated. A short analysis of the facts in either case will readily explain to what these discrepancies are attributable; but it will be necessary to have recourse to a diagram.

"Let A B, Fig. 38, be a plain mirror upon which the rays of light R impinge; they will be reflected uniformly to R′, forming a clear image. Now let A B C D E F G be another reflecting surface, having two convexities, B C, E F, and one concavity in the centre D (the condition nearly of the brass button). In this case the light reflected from the outer concave flexures of the protruding portion of the surfaces B C, E F, will converge in the foci *b c* and *e f* respectively, at distances corresponding to the radius of their curvature; the effect will, of course, be visible within wide limits of the actual focus. In most of the buttons, however, the central depression is so great that it collects the rays in a focus, *d*, a few inches only in front of the surface; and when the spectrum is thrown farther off, the rays crossing from two less distinct luminous foci, *d′ d′*, it follows from analogy that the thin parts or tympanum of the Japanese mirror are slightly convex with reference to the rest of the reflecting surface, which may have been caused either by the ornamental work being stamped or partially carved with the hammer and chisel on its back, or, what is more probable, that part of the metal was by this stamping rendered harder, so that in polishing it was not worn away to the same extent."

Since the above was written, an English brass-finisher appears to have discovered the secret. Taking ordinary brass, he finds that any figure stamped upon it with a proper die, and ground down and polished, will not reflect the figure impressed by the die; but if the process with the same die is repeated *three times*, so that the figure intended to be projected from the surface is stamped three times in the same place, and subsequently ground down and polished after each stamping, then a molecular difference is established between

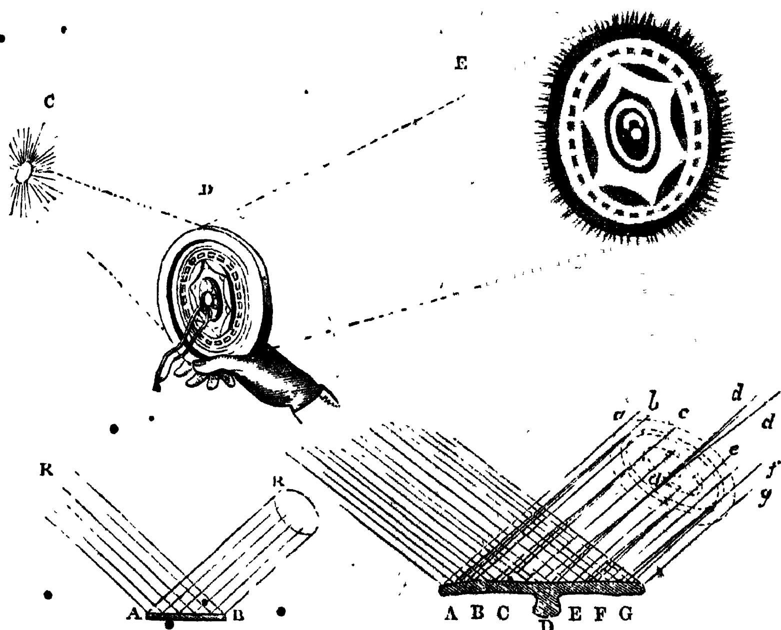


FIG. 38.

the stamped and unstamped parts, which is not apparent to the eye, but is shown directly the surface so acted on is used for reflecting light.

There can be no doubt that, until the magic lantern was invented, the only optical apparatus used by persons who pretended to wield the "magic art" consisted of plane and concave mirrors. The memoirs of Monsieur E. J. Robertson, published in Paris in 1831, disclose some amusing applications of surfaces that reflect light, and he describes how the magician Nostrodamus deceived the politic Marie de Medicis, and pretended to show the astute queen the king for whom the throne of the Bourbons was destined. He states that Marie de Medicis, disquieted by apprehensions regarding the succession to the throne of France, went to consult Nostrodamus. This dealer in miracles by the use of plain mirrors produced the effect shown in Fig. 39, p. 40.

La Boîte Magique.—The magic box is another amusing example of the same kind, only in this case a concave mirror is employed instead of a plane one. This experiment, Robertson declares, is charming, and having, he says, told a lady the secret of several illusions which pleased her greatly, he happened to be staying with the same individual in the country, at the time that a most agreeable gentleman was paying his court to her; the latter said to her lover, "If you do not fear apparitions, I promise you one this evening which may please you. At twelve precisely open the box that you

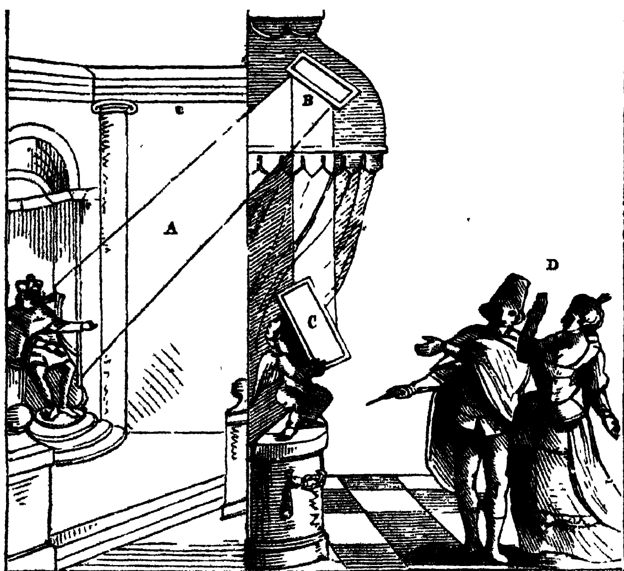


FIG. 39.
The throne, placed in the first apartment A, is reflected by a mirror concealed in the canopy B, Marie de Medicis beholds the representation of the image in a mirror C, supported by a Cupid.

will find on your table, of which this is the key, and my image will come out of the box." This promise seemed only an agreeable kind of banter to her gallant, and, though he promised to open the box, he feared to do so, lest he might be made the dupe of some trick. At first he would not touch it, but at last, yielding to curiosity, he opened the box, when the image of his lady-love immediately appeared, with a very grave and composed air; but she, guessing that the countenance of her gallant must bear a strange — a serio-comic, though interesting—expression, forgot that silence was necessary, and, bursting out into laughter, was thus discovered in the adjoining room.

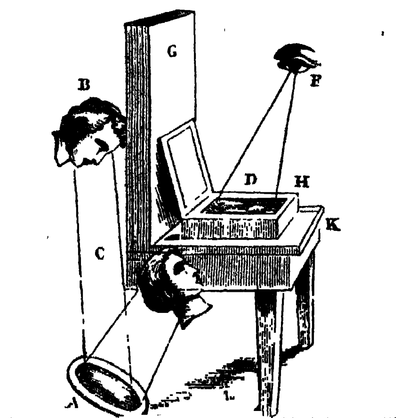


FIG. 40.
A, concave mirror; the head B, inclined towards C, appears to emerge from D, to an eye placed at F; the head, B, must be well illuminated, and the mirror in the shadow, so that it may not be visible; G is the wall; at H a box to open, firmly fixed on a table K. The interior of the box is painted black, and of course the wall which separates the two apartments is open under the table.

The ancients made use of concave mirrors to rekindle the vestal fires. Plutarch says they employed σκαφεια, or dishes, for that purpose. They were, most likely, hemispherical vessels highly polished within.

As an illustration of the more refined uses and applications of silvered mirrors, may be quoted the admirable instructions given by Mr. John Browning, of 111 Minories, for adjusting and using reflectors for astronomical telescopes with *silvered-glass specula.*

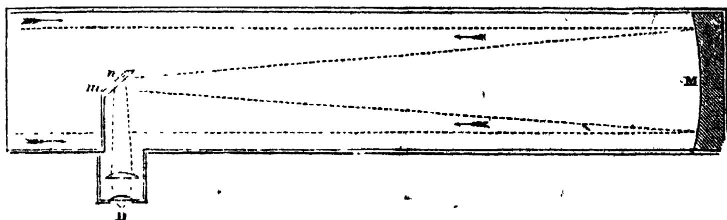


FIG. 41.

MR. BROWNING'S DESCRIPTION OF THE SILVERED GLASS REFLECTING TELESCOPES.

These telescopes are of the kind called Newtonian, a form so well known, that it is, perhaps, scarcely necessary to describe it; but I append a plain diagram (Fig. 41) and brief description, because it will assist in making clearer the instructions I have given further on, of the method of adjusting the instrument. The Newtonian telescope consists of a tube closed at the lower end, which is occupied by a concave mirror, M. The cone of rays reflected from this mirror is again reflected at right angles from the surface of a small plane mirror, *m n*, mounted at an angle of 45°, near the open end of the tube, into the eye-piece, which is exactly opposite.*

In reflecting telescopes, as originally constructed, the concave mirror was made of an extremely hard alloy, known as speculum metal. These metallic mirrors possessed several disadvantages, so serious in character that they have for some time fallen out of general use. The principal defects were the following:

1. From the extreme brittleness of the alloy, they were very liable to fracture, sometimes breaking merely from a sudden change of temperature.

2. From their great weight it was extremely difficult to mount them in such a way as to prevent flexure, the smallest amount of which greatly injured their optical performance.

3. Their greatest drawback, however, consisted in the fact that the surface of the metal, from damp or other causes, sometimes became very rapidly tarnished, and this tarnish could seldom be removed, except by repolishing and, consequently, refiguring the mirror; and this involved nearly as great an outlay as the purchase of a new speculum, besides incurring the serious risk of a fine figure being irretrievably lost.

In the telescope now described, the metallic mirror is replaced by one of

* The mirror must not be worked to a spherical, but to a very perfect parabolic curve.

glass, on the surface of which a coating of pure silver has been deposited by Liebig's process, and described further on.

These glass mirrors are not at all injuriously affected by change of temperature, and their lightness very considerably reduces their liability to flexure; indeed, mounted in the manner I shall presently describe, no flexure has ever been observed in them. I may, however, state that I make the discs of the specula, which Mr. With parabolizes for me, out of glass nearly twice the substance of that generally used for the purpose. The coating of pure silver reflects fully one-third more light than the best speculum metal, as the alloy before mentioned is called. But the greatest superiority of silvered glass over metallic mirrors consists in the fact that, should they become tarnished, their brilliancy may readily be restored by gentle friction with soft leather and a little of the finest rouge; and even should the silver coating become utterly spoiled, it may be easily removed without in any way impairing either the figure or polish of the glass speculum, and a fresh one deposited at a trifling cost, thus making the mirror equal to new; and this may be repeated indefinitely. Should the owner possess a little patience, he may renew the coating himself at the cost of only a few pence. The silvering process is fully described further on.

With this alteration these telescopes have latterly gained much ground in the opinion of practical observers well known in the scientific world, who have had considerable experience in working with them.

On figuring Specula.—About three years since, the Rev. Cooper Key discovered a more simple method of parabolizing the surface of specula than any which had hitherto been employed, and by this process he produced two fine specula of 12 in. diameter.

The process by which these specula were worked Mr. Key communicated to Mr. G. With, and after having worked by Mr. Key's process until a few months since, Mr. With at length contrived another plan of working, by which he considers still finer results are with greater certainty secured.

The wonderful perfection of Mr. With's specula is now generally admitted, and it is almost certain that they surpass any that have previously been produced. I have great pleasure in stating that specula of Mr. With's parabolizing are now only to be obtained from me.

On mounting Specula.—It has elsewhere been suggested that much of the dissatisfaction which has been expressed by those who have used reflectors has arisen from their having been imperfectly mounted.

Because specula are much cheaper than achromatic object-glasses, it has been supposed that they could be mounted at proportionately less cost than that incurred in mounting reflectors. This is only true to the extent that cost can be saved by reason of their shorter focal length.

It cannot be too strongly enforced that, to give the best performance, reflectors require to be mounted more steadily than refractors, because by a well-known law of optics the effect of any vibration will be multiplied many times. Their tubes must also be carefully arranged, so as to avoid as much as possible the interference of air-currents, which are the bane of reflectors improperly mounted or badly situated. The specula in the telescopes ... described are mounted rigidly on a new plan, which ensures permanence in adjustment and prevents flexure. This plan is represented in Fig. 42.

The bottom of the speculum A is a carefully prepared plane surface, and the bottom of the inner iron cell B, on which it rests, is also a plane. The

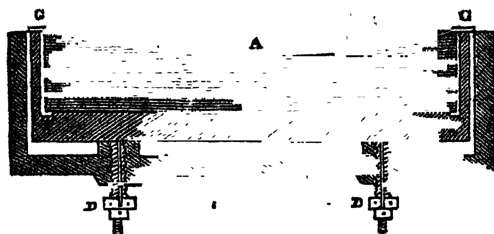


FIG. 42.

speculum is clamped in this cell by the ring G G, and it may be removed from and replaced in the telescope without altering its adjustment. The elastic methods of mounting the speculum, which have hitherto been employed, generally required re-adjustment whenever the speculum had been removed. The reflecting diagonal prism or mirror is mounted in the manner shown in the diagrams Figs. 43 and 44.

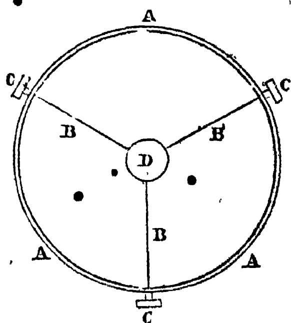


FIG. 43.

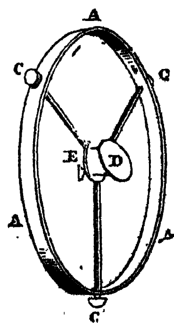


FIG. 44.

In these B B B represent strips of strong chronometer spring steel, placed edgewise towards the speculum, by which the prism or small mirror D is suspended.

The mirror, thus mounted, does not produce such coarse rays on bright stars as when it is fixed to a single stout arm; it is also less liable to vibration, which is very injurious to distinct vision, or to flexure, which interferes with the accuracy of the adjustments.

If an observer determines to lay out a given sum in the purchase of a telescope, he will find it to his advantage to have a smaller speculum completely mounted, instead of a large speculum imperfectly mounted. With the smaller and perfect instrument he will really do more work, and with much greater comfort and satisfaction to himself. No matter how good a speculum may be, nothing can be told of its performance on difficult double stars if it is mounted on an unsteady stand.

The alt-azimuth stand, represented in Fig. 45, is entirely of iron. The tube of the telescope is of extremely stout block tin, coloured dark green, the stand being coloured dark chocolate. The body is equipoised, so that it will remain in any position, while the movements are so smooth, and the leverage so arranged, that a star may be followed, even with a power of 300, without screw motions. The instrument can be used on a table, at any window; and a stand is supplied with it, on which it can be supported at a convenient height when it is used in the open air. This mounting is only adapted for a small-sized speculum, say not exceeding 5 in. in diameter, as, if made of a larger size, it

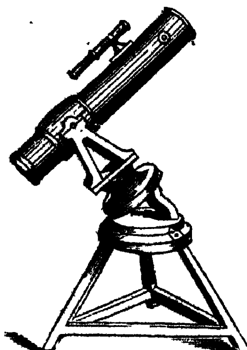


FIG. 45.—*The small Alt-azimuth.*

would be so heavy as not to be portable; while with higher powers than 300, such as specula of 6 in. and above will easily bear, the celestial bodies cannot be followed without screw motions. By fastening the circular foot down on a block of wood of a wedge form, the angle being the complementary angle to the latitude of the place, this stand can very readily, and at a comparatively trifling expense, be made to move equatorially, so that the heavenly bodies can be followed with a single motion of the telescope. Such an arrangement is shown in Fig. 45. A cheaper mounting is shown in Fig. 54.

The 4½-inch silvered-glass speculum, with powers from 100 to 150, will divide—

β Orionis. α Lyræ.
δ Geminorum. ε Hydræ.
ξ Ursæ Majoris.
ε Bootis.
ν Ceti. ε Draconis.

The 6½ will divide, with powers from 200 to 300—

ε Arietis. α Herculis.
ξ Bootis. 32 Orionis.
ι Equulei. η Coronæ Borealis.
36 Andromedæ.

The 8½, with powers from 300 to 350, in a favourable state of the air, will divide—

γ^2 Andromedæ.
μ Bootis.

These last-named double stars are both under half a second apart, and are so difficult to divide as to have hitherto been considered good work for a 12-inch speculum.

TO SILVER GLASS SPECULA.

Prepare three standard solutions:—

Solution A	Crystals of nitrate of silver .	90 grains	Dissolve.
	Distilled water	4 ounces	
Solution B	Potassa, *pure by alcohol* . .	1 ounce	Dissolve.
	Distilled water	25 ounces	
Solution C	Milk-sugar, in powder . . .	½ ounce	Dissolve.
	Distilled water	5 ounces	

Solutions A and B will keep, in stoppered bottles, for any length of time; solution C must be fresh.

The Silvering Fluid.—To prepare sufficient for silvering an 8-inch speculum, pour 2 ounces of solution A into a glass vessel capable of holding 35 fluid ounces. Add, drop by drop, stirring all the time with a glass rod, as much liquid ammonia as is *just* necessary to obtain a clear solution of the grey precipitate first thrown down. Add 4 ounces of solution B. The brown-black precipitate formed must be *just* re-dissolved by the addition of more ammonia as before. Add distilled water until the bulk reaches 15 ounces, and add, drop by drop, some of solution A, until a grey precipitate, which does not re-dissolve after stirring for three minutes, is obtained, then add 15 ounces more of distilled water. Set this solution aside to settle. Do not filter.

When all is ready for immersing the mirror, add to the silvering solution 2 ounces of solution C, and stir gently and thoroughly. Solution C may be filtered.

Perfectly pure chemicals may be obtained of Mr. Townson, 89, Bishopsgate Within, London, E.C., and Mr. R. Thomas, 10, Pall Mall.

To prepare the Speculum.—Procure a circular block of wood 2 in. thick and 2 in. less in diameter than the speculum. Into this should be screwed three eye-pins at equal distances, as in Fig. 46. To these pins fasten stout whipcord, making a secure loop at the top.

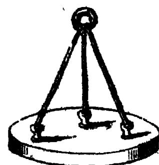


FIG. 46.

Melt some soft pitch in any convenient vessel, and having placed the wooden block face upwards on a level table, pour on it the fluid pitch, and on the pitch place the back of the speculum, having previously moistened it with a thin film of spirit of turpentine to secure adhesion. Let the whole rest until the pitch is cold.

To clean the Speculum.—Place the speculum, cemented to the circular block, face upwards, on a level table; pour on it a small quantity of strong nitric acid, and rub it gently all over the surface with a brush made by plugging a glass tube with pure cotton wool. (Fig. 47.) Having perfectly cleaned the surface and sides, wash well with common water, and finally with distilled water. Place the speculum face downwards in a dish containing a little rectified spirit of wine until the silvering fluid is ready.

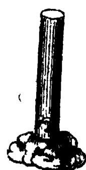


FIG. 47.

To immerse the Speculum.—Take a circular dish about 3 in. deep and 2 in. larger in diameter than the speculum. Mix in it

the silvering solution and the solution C, and suspend the speculum, face downwards, in the liquid, which may rise about a quarter of an inch up the side of the speculum.

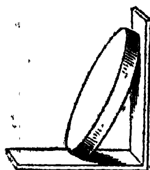


FIG. 48.

When the silvering is completed, remove the speculum from the solution, and immediately wash with plenty of water, using at least two gallons, and finally with a little distilled water. Place the speculum on its edge on blotting-paper to drain and dry. (Fig. 48.)

When perfectly dry, polish the film by gently rubbing first with a piece of the softest wash-leather, using circular strokes (Fig. 49), and finally with the addition of a little finest rouge.*

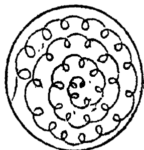


FIG. 49.

A "flat" may be silvered by fastening with pitch to a slice of cork, cleaning as above described, and using as much silvering fluid as will form a stratum about half an inch deep beneath the mirror.

To separate the Speculum from the Block.—Stand the speculum on its side, insert the edge of a sharp half-inch chisel between the wood and glass, administering two or three gentle blows, and the block and mirror will separate safely and easily. It is preferable to obtain the aid of an assistant in this operation. Any pitch which remains on the back of the mirror may be removed by scraping and a little turpentine.

The cost of silvering an 8-inch speculum, exclusive of the cost of alcohol, which may be used over and over again, will not exceed 9d.,

Nitrate of silver being 4s. per oz.
Potash . . 8d. "
Milk-sugar . 2d. "

Avoid all excess of ammonia, and be sure to use *pure* distilled water.

ON WORKING GLASS SPECULA.

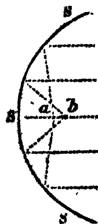


FIG. 50.

When parallel rays of light are allowed to fall upon the surface of a concave mirror, if the surface be a spherical curve, the rays will not all be reflected to a single point.

In Fig. 50 it will be seen

* The silvering will be completed in from 50 to 70 minutes, according to temperature; 50 minutes will be sufficient in summer.

reflected and form an image at *a*; while the rays B B would be reflected and form an image at *b*, farther from the front of the mirror.

If the reflected images were viewed with an eye-piece placed anywhere in front of the mirror, they would not be in focus at the same time, so that only a blurred and indistinct image would be seen.

To make the mirror reflect rays falling on all parts of its surface to one point, it is necessary that it should be fashioned into a parabolic curve.

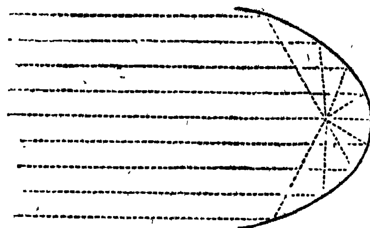


FIG. 51.

Such a curve is shown in Fig. 51, which may be considered as a spherical curve, in which the curve has been made deeper or the outer portion flattened. In practice the amount of this difference is so exceedingly minute as to be inappreciable by actual measurement.

Sir John Herschel states that the utmost variation of a 4-foot speculum from a spherical curve is less than than one 21,000th part of an inch. Yet it is well known that for telescopic use a mirror with a spherical curve is, for the reason just explained, totally useless.

In working the glass specula, a disc of hard crown glass, varying in substance from three-quarters of an inch to one and a half inches, according to the size of the speculum for which it is intended, is turned, and polished on the edge. One side of this disc is ground to a truly plane surface. On this side the speculum, when mounted on the writer's plan, rests in its cell. The other side is then ground to a concave spherical curve of such a radius as will produce the desired focus. This spherical curve is converted into a parabolic figure somewhat thus:

An iron tool, similar to that on which the spherical curve has been ground, is covered with a layer of pitch, tempered to a certain consistency. This pitch is warmed, and the speculum being laid upon it makes the pitch assume the same curve. The speculum is then polished on the pitch with rouge. In this polishing the speculum and polisher are not worked together equally all over the surfaces, but the speculum is moved in such a manner that it is polished away most towards the edge, and a parabolic curve is produced. During the process both the speculum and the polisher continually revolve.

The diagram of Lord Rosse's machine, with which he figured his speculum 6 ft. in diameter, will give an idea of the action of the speculum and polisher on each other.

This machine is represented in Fig. 52; A is the spindle, by turning which the whole machine is set in motion; H I is the speculum; K L, the polisher; B, an excentric which carries the polisher backwards and forwards; G, another excentric which moves the polisher from side to side slowly during the recipro-

cating motion. The amount of motion given to the polisher, and the rapidity of rotation of the speculum, can be changed at pleasure.

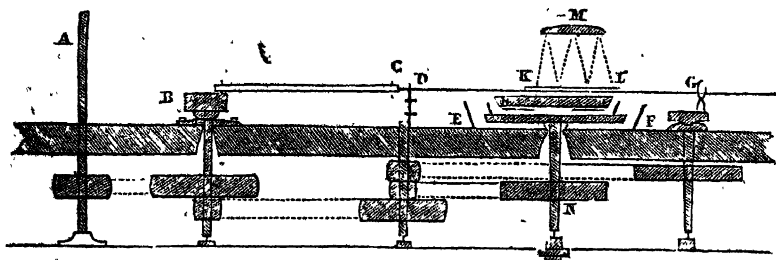


Fig. 52.

In Fig. 53 the dotted line represents the spherical curve of the mirror when the polishing is begun, and the continuous line the parabolic curve it assumes when the polishing process is finished. It will be, of course, understood that in all the diagrams these curves are enormously exaggerated.

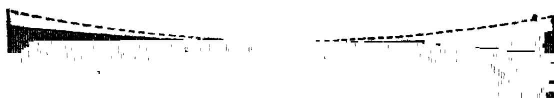


Fig. 53.

During the graduated polishing the speculum is repeatedly tested, until the desired definition is attained. When completed, if accurately figured, the marginal inch of the speculum should give equally sharp definition with the centre, and have identically the same focus.

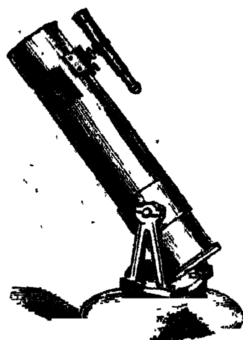


FIG. 54.

In figuring the mirrors of the telescopes herein described, an improved method has been adopted of fashioning the parabolic curve; it is believed this method gives superior results to any hitherto attained.*

* The reader who wishes for further information on this subject is referred to Sir John Herschel's work on "The Telescope."

THE REFRACTION OF LIGHT.

When a ray of light passes from one medium to another of the same density, and in a perfectly straight line, no alteration of its course takes place; but if the light passes in an oblique direction, its course is broken or *refracted*, *i.e.*, bent back from its natural path. To this branch of optics, which includes, perhaps, the widest field of inquiry, and traces the propagation of light through transparent, solid, liquid, and gaseous bodies, has been given the name of

DIOPTRICS.

To prove that a straight line representing a ray of light is really bent when passing from a rare medium, air, into a denser one, such as water, nothing is easier than to place a bright shilling on the end of an ivory paper-knife, which is inclined in a large empty tumbler. On looking down the paper-knife a straight line only is apparent, terminating with the coin; but if the tumbler is filled with water whilst the observer is still looking down the flat surface, he

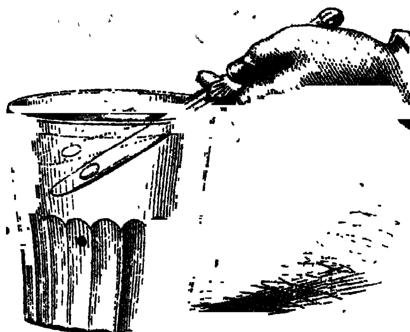


FIG. 55.—*A simple demonstration of the property of Refraction.*

will notice that at the point of juncture between the air and water a break takes place, and the end of the paper-knife, or all that part immersed, appears to be lifted up or bent upwards from its natural course or direction. If a small pocket-pistol were now aimed at the coin and the bullet discharged it would certainly miss, because every visible object appears to be in a direction represented by a straight line drawn from it to the eye. A straight line ruled to the shilling would not touch it, the line must be ruled to, or the pistol aimed at, a point nearer to the spectator than the apparent position of the coin.

The bending of the ray is governed by certain laws known as "Descartes' Laws."

Firstly, Whatever the obliquity of the incident ray, the sine of the incident angle and the sine of the angle of refraction are in a constant ratio for the same two media, but vary with different media.

Secondly, The incident and the refracted rays are in the same plane, which is perpendicular to the surface separating the two media.

A very complete French apparatus (Fig. 56), described in Ganot's "Physics,"

is made for the purpose of proving those laws experimentally. It consists of a large and carefully graduated circle supported on a tripod stand. In the centre is placed a semi-cylindrical glass vessel filled with water, or any other fluid whose index of refraction it is required to ascertain, so that the level of the fluid coincides with the height of the centre of the circle. From the mirror A, a ray of light is reflected through a hole in the screen B, and falls on the surface of the water at C. Passing through the water, the course of the refracted ray is traced to a screen D, on which the circular image is received. In the various positions of the screens B and D, attached to arms radiating from the centre C, the sines of the angles of incidence and refraction are obtained and measured by two graduated rules E F, movable so as to be always horizontal, and therefore perpendicular to the diameter G H.

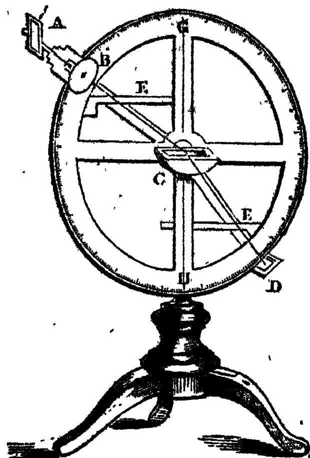


FIG. 56.

The numbers vary with the positions of the screens, but the sines of the incident and refracted rays are in a constant ratio to the same two media, viz.; air and water. If the sine of the incident ray is doubled, the sine of the refracted one will increase in the same ratio.

When another fluid is put into the trough, a variation in the sines would occur, and it is in this manner the first law is proved. By moving the mirror and screen B, so that the light falls perpendicularly on the surface of the water, the instrument proves the second law, as there cannot then be any angle formed, or sines to record or measure.

Supposing the sine of the angle of refraction in the above experiment with air and water to measure 12 in., and the sine of the angle of incidence 16 in., it would follow that in water the sine of the angle of incidence is to the sine of the angle of refraction as 1·336 to 1, or as nearly as possible $1\frac{1}{3}$ to 1. The number 1·336, which expresses this ratio for water, is called the *index of refraction* for water, and sometimes its *refractive power*.

The determination of the refractive powers of various kinds of glass is of great use in the manufacture of achromatic telescopes; and sometimes the purity of a liquid, and its freedom from adulteration, may be approximately ascertained by taking the index of refraction.

In the chapter devoted to the consideration of the reflection of light, it was thought to be the most simple and instructive plan to trace the progress of *parallel* rays when thrown off from plane, concave, or convex surfaces.

The forms of refracting bodies, and their action on light, are so numerous and well discussed in the more elaborate works on Dioptrics, that it is mere repetition to quote them all.

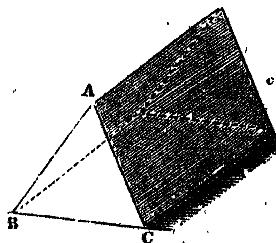


FIG. 57.

The laws of refraction being known, and the refractive power of the glass used for experiment

being ascertained, the mathematician may work out on paper the exact direction of the light passing into or out of the most complicated forms. As an illustration of this mode of investigation, the following instructions are given by Brewster, in order to enable the student to study the refraction of light through one of the most important optical instruments, viz., the Prism. (Fig. 57.)

An optical prism, a solid having three plane surfaces. A B, A C, called its refracting surfaces; B C is called the base of the prism.

Let A B C (Fig. 58) be a prism of plate glass, whose index of refraction is 1·500, and let H R be a ray of light falling obliquely upon its first surface A B at the point R. Round R, as a centre, and with any radius H R, describe the circle H M *b*. Through R draw M R N perpendicular to A B, and H *m* perpendicular to M R. The angle H R M will be the angle of incidence of the ray H R, and H *m* its sine, which in the present case is 1·500. Then, having made a scale in which the distance H *m* is 1·500, or 1½ parts, take one part or unity from the same scale, and having set one foot of the compasses on the circle, somewhere about *b*, move it to different points of the circle till the other foot strikes only one point *n* of the line R N; the point *b* thus found will be that through which the refracted ray passes, R *b* will be the refracted ray, and *n* R *b* the angle of refraction, because the sine *b n* of this angle has been made such, that its ratio to H *m*, the sine of the angle of incidence, is as 1 to 1·500. The ray R *b* thus refracted will go on in a straight line till it meets the second surface of the prism at R R′, when it will again suffer refraction in the direction R *b*′. In order to determine this direction, make R′ H′ equal to R H, and, with this distance as radius, describe the circle H′ *b*′. Draw R′ N perpendicular to A C, and H′ *m*′ perpendicular to R N, and form a scale on which H′ *m*′ shall be one part, or 1·000, and divide it into tenths and hundredths. From this scale take in the compasses the index of refraction 1·500 as 1½ of these parts; and, having set one foot somewhere in the line R′ *n*′, move it to different parts of it till the other foot falls upon some part of the circle about *b*′, taking care that the point *b*′ is such, that when one foot of the compasses is placed there, the other foot will touch the line R′ *b*′, continued only in one place, join R′ *b*′. Then, since H′ R′ *m*′ is the angle of incidence, or the second surface A C and H′ *m*′ its sine, and since *n*′ *b*′, the sine of the angle *b*′ R *n*′, has been made to have to H′ *m*′ the ratio of 1·500 to 1, *b*′ R′ *n*′ will be the angle of refraction, and R′ *b*′ the refracted ray. In the construction of the figure (Fig. 58) the ray H R has been made to fall upon the prism at such an angle that the refracted ray R R′ is equally inclined to the faces A B, A C; or is parallel to the base B C of the prism; and it will be found that the angle of incidence H R B is equal to the angle of emergence *b*′ R′ C. Under these circumstances, we shall find, by working the angle H R B either greater or less than it is in the figures, that the angle of deviation H E D is less than at any other angle of incidence. If we, therefore, place the eye behind the prism at *b*′, and turn the prism round in the plane B A C, sometimes bringing A towards

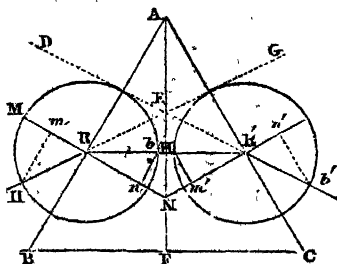


FIG. 58.

the eye and sometimes pushing it from it, we shall easily discover the position when the image of the candle seen in the direction b' D has the least deviation. When this position is found, the angles H R B and b' R′ C are equal, and R R′ is parallel to B C, and perpendicular to A F, a line bisecting the refracting angle B A C of the prism; but since B A F is known, the angle of refraction B R N is also known; and the angle of incidence H R B being found by the preceding methods, we may determine the index of refraction for any prism by the following analogy:—

As the sine of the angle of refraction is to the sine of the angle of incidence, so is unity to the index of refraction; or the index of refraction is equal to the sine of the angle of incidence divided by the sine of the angle of refraction. By this method we may readily measure the refractive power of all bodies. If the body be solid, it must be shaped into a prism; and if it is soft or fluid, it must be placed in the angle B A C of a hollow prism, A B C, (Fig. 59) made by cementing together three pieces of plate glass, A B, A C, B C. A very simple hollow prism for this purpose may be made by fastening together at any angle two pieces of plate glass, A B, A C, with a bit of wax F. A drop of the fluid may then be placed in the angle at A, when it will be retained by the force of capillary attraction.

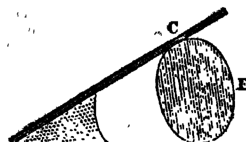


FIG. 59.

TABLE OF THE INDICES OF REFRACTION.

Vacuum	1·000000	Lens, Crystalline	1·384
Air	1·000294	„ Vitrous	1·339
Albumen	1·360	„ Aqueous	1·336
Alcohol	1·374	Nitrous Oxide Gas	1·000503
Ammonia Gas	1·000385	Nitric Acid	1·410
Alum	1·457	Oxygen	1·000272
Amber	1·547	Olefiant Gas	1·000678
Bisulphide of Carbon	1·678 *	Oil, Olive	1·470
Carbonic Acid Gas	1·000449	„ Turpentine	1·475
Chlorine Gas	1·000772	„ Castor	1·490
Diamond	2·439	„ Cloves	1·535
Ether	1·358	„ Cassia	1·641
Fluid Spar	1·434	Phosphorus	2·424
Glass, Flint	1·605	Quartz	1·548
„ Plate	1·543	Ruby	1·779
„ Crown	1·534	Sapphire	1·794
Garnet	1·815	Sulphur	2·115
Hydrogen	1·000138	Sulphuric Acid Gas	1·000665
Hydrochloric Acid Gas	1·000449	Sulphuric Acid	1·434
Hydrochloric Acid	1·410	Tabasheer	1·111
Iceland Spar—		Water	1·336
Ordinary ray	1·654	„ Solid (Ice)	1·310
Extraordinary ray	1·483	Zircon	1·961

rays of light through plane, concave, and conve

* Used to fill prisms for spectrum analysis.

surfaces of glass may now be considered, and they will be found to contrast in the most simple manner with similar-shaped reflecting surfaces.

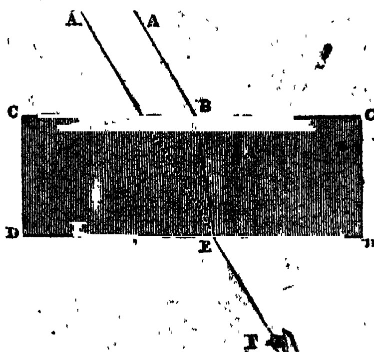


FIG. 60.

REFRACTION OF LIGHT THROUGH PLANE GLASS.

Let A B (Fig. 60) be a ray of light incident on the upper surface or side of a piece of ordinary plate glass, marked C C, whose other or under side, D D, is parallel to C C. On entering the glass the ray is refracted in the direction B E, and it will be refracted again at its exit from the under side, D D, to the same amount as at its entrance in the line E F; consequently an eye placed at F would see the ray as if it came from the point A′ along the line F E A′. The light has undergone refraction, and an object seen through a window is not seen in its true position; but, as parallel rays falling upon a plane glass retain their parallel lines after passing through it, the object does not appear to undergo any change unless the two surfaces of the glass are uneven, and not parallel with each other, when distortion takes place. Such an effect is rarely seen now in looking through the windows of good houses, because they are usually glazed with plate glass, the sides of which are nearly parallel. It has already been shown that convex mirrors (page 22) render parallel rays of light divergent; precisely the reverse occurs with convex refracting surfaces.

REFRACTION OF PARALLEL RAYS OF LIGHT BY CONVEX SURFACES.

Fig. 61 represents a piece of glass cut into the form of a double-convex lens A B, a figure such as would be produced by placing one watch-glass on the edge of another having precisely the same amount of convexity. Let C D be a ray of light falling perpendicularly on the refracting surface and passing straight through the glass, in obedience to the law already enunciated, that a ray of light which falls perpendicularly on a refracting surface undergoes no change in its direction, and therefore C D passes through the middle or axis

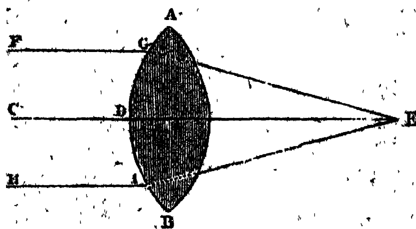


FIG. 61.

of the crystal lens without deviation from a straight line C D E. The other two rays, F G, H I, falling at an angle on the glass, undergo refraction, and are bent towards and emerge from the other side, and meet at the point E, called the principal focus, or focus for parallel rays. These parallel rays of light are refracted by a double-convex lens, and become convergent, meeting at a point called the focus. On the other hand, if E be considered as the luminous point from which divergent rays are emitted, they become parallel rays when they emerge from the double-convex lens A B.

REFRACTION OF PARALLEL RAYS BY CONCAVE SURFACES.

Let A B (Fig. 62) be a glass lens, whose two sides are hollowed out, or concave, and C D a ray of light falling perpendicularly on the surface, and therefore passing straight through the lens. F G and H I are two other rays impinging on the surface of the glass at an angle; these undergo refraction, and are bent outwards in the direction F G K and H I K.

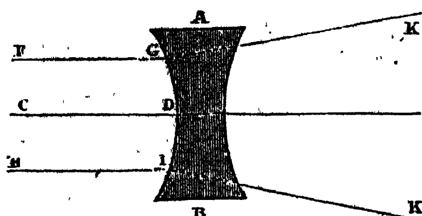


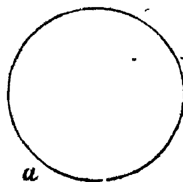
FIG. 62.

Thus the property of a concave lens is just the reverse of a concave mirror, the former causing parallel rays of light to become divergent, the latter convergent; and if the rays K K be regarded as convergent rays, they become parallel when emerging from the concave lens A B.

OTHER FORMS OF LENSES.

For various optical purposes a variety of lenses, in addition to the prism, the double convex, or the double concave lenses, is required, which may be ground into the following forms:

a. A spherical lens, causing parallel rays to become convergent . . . .



b. A plano convex lens; parallel rays become convergent . . . .

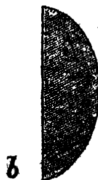


FIG. 63.

c. A plano-concave lens; parallel rays become divergent . . . .



d. A meniscus; parallel rays become convergent .



e. A concavo-convex lens; when the concavity exceeds the convexity, parallel rays become divergent .



FIG. 63.

It is good practice for the student in physics to make careful drawings of the above figures, and to trace the paths of imaginary rays of light through them. The drawings may be varied by supposing the lenses to be made of any of the solid transparent substances whose refracting indices are given in the table at page 52.

OPTICAL INSTRUMENTS WHOSE PROPERTIES DEPEND ON REFRACTION.

THE SIMPLE AND COMPOUND MICROSCOPE AND TELESCOPE.

It follows from the laws of refraction already explained, that when a double-convex lens (Fig. 64) acts on rays proceeding from an object, such as a candle, A B, that, as the rays are not all parallel, they will be collected into a focus A′ B′ at a distance behind the lens somewhat greater than the focus for parallel rays at E, and that an inverted image of the candle A B will be produced at A″ B′, which may be received on any white surface. Thus a double-convex lens becomes the most simple microscope which can be used, and it is sometimes used for that purpose in the examination of samples of wheat. The

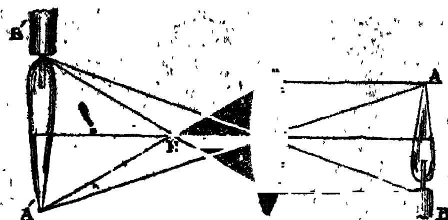


FIG. 64.

cheapest microscope the author has seen is that made by Mc Culloch, of Blucher Street, Birmingham, for half-a-crown. It includes a lens made, seemingly, of a filament of glass melted into a globule, fitted into a brass tube which contains a plate of glass to be used as an object-holder (such as for the eels in paste), and the opposite end of the brass tube is closed with a diaphragm, which can be unscrewed if more light is required. The whole is fitted into a case, and might be made a very amusing companion for young people when they go into the fields; and if lost, the value is not an alarming consideration. Another marvel of cheapness is a telescope made by Solomon, of Albemarle Street, at a cost of five shillings. The latter, of course, is not achromatic; but its definition of distant objects is really excellent, and the workmanship good.



Fig. 65. *Simple Microscope*, in which the Lens is focused by turning the Screw.

In the compound microscope the image A′ B′ (Fig. 64) is still further magnified, and can be more carefully examined by the addition of another double-convex lens, say of an inch focal distance. It is the image formed in the tube of the compound telescope, which may be again magnified by employing a second lens with a very short focus. In these cases the first lens is called the object-glass, and the second the eye-piece or glass. Of late years the most elaborate and perfect microscopes have been made in this country; so that England stands unrivalled in this branch of optical instruments, whilst her microscopical societies have contributed largely to our knowledge of those things which cannot be appreciated or examined without the use of these contrivances.

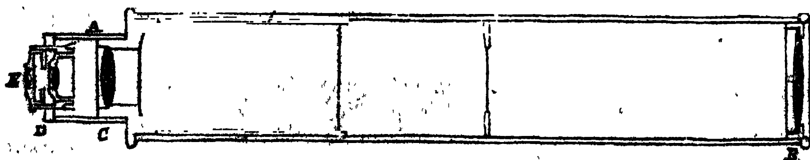


FIG. 66.—*The Compound Telescope.*

B, The object-glass, which throws an inverted image into the dark tube; C is the eye-glass, which magnifies the inverted image. This telescope could only be used for astronomical purposes; but, by the addition of two other convex lenses at D E, called erecting-glasses, an erect image is obtained.

THE CAMERA OBSCURA.

A dark chamber into which a double-convex lens is fitted. The invention of this pleasing contrivance has been usually ascribed to Baptista Porta, as it appears in his "Magica Naturalis," lib. xvii., cap. vi., first published at Frankfort about 1589 or 1591.

Fifty years ago the camera obscura was more popular than it is now, and was frequently erected on elevated spots of ground by wealthy individuals, the consequence being that the whole apparatus and the building to which it was attached were most carefully made and adjusted to each other.

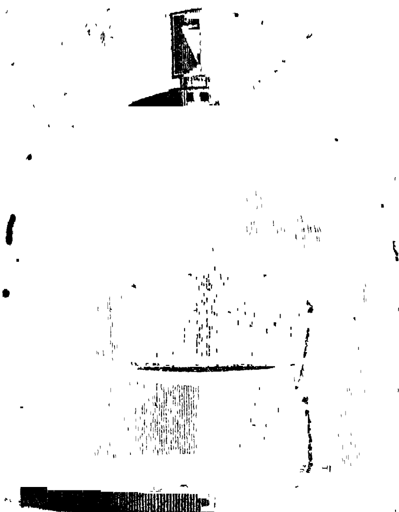


FIG. 67.

Fig. 67 represents a dome or cupola placed over a room erected for the purpose of a camera obscura. The whole dome, which carries the box and containing a mirror placed at an angle over a double-convex lens, may be made to turn round on friction-wheels; or, what is more simple, the box is made movable in a groove upon the dome, and may be turned with a long rod by a person inside. The box is recommended to be of a cubical form, of about 6 or 7 in. square, and contains a carefully ground plain silvered mirror, which should be made of parallel glass placed diagonally in the box; the mirror itself should be attached by hinges at the lower end, so that a different angle may be obtained if required. Underneath the mirror, in a round cell at the bottom of the box, is fixed a double-convex lens, about 6 or 8 ft. focus and 4 or 5 in. in diameter; this lens will form, upon a white table

placed on the floor below, the image of the objects reflected by the mirror above at the focal distance of the lens. The diameter of the table should be $2\frac{1}{2}$ or 3 ft., and, in order to correct the indistinct images formed at the edge by spherical aberration, it is usual to make the surface slightly concave, and to form it of the best plaster of paris or stucco. The table should be supported by a pillar in the centre, fitting into a tube provided with a screw, so that the table may be raised or lowered, and the images exactly focused on its surface. A still more perfect optical arrangement for projecting brilliant images of distant objects on to a white surface for the purposes of the artist is shown in the figure annexed. (Fig. 68.)

FIG. 68.—*The Prism Camera.*

D D D, section of a pyramidal box; M, a brass tube open on one side, moving in another tube, and containing the rectangular prism A B C, one side of which, A C, is convex, and the other, C B, concave; O, the framework to support the sheet of paper.

In this camera the rays of light, after falling on the convex surface, enter the prism, and, being totally reflected from the side A B, pass into the box through the concave surface, and fall upon a sheet of paper laid out on a proper framework. The picture thus obtained has not the fault of those produced by the ordinary arrangement of the mirror or convex lens, being free from spherical aberration, which is neutralized in this instance by the concave surface of the prism. As these prisms are difficult to make, the same result is attained by carefully cementing with Canada balsam a plano-convex lens on one side of the prism, and a plano-concave on the other, whose focal lengths are equal to each other. (Fig. 69.)

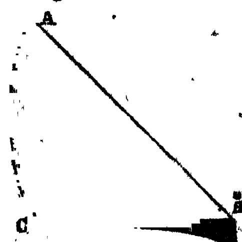


FIG. 69.

A B C, the prism, with plano-convex and plano-concave lens attached at A B and C B.

The magic lantern apparatus, the dissolving view and the phantasmagoria lantern apparatus, are all refracting optical instruments, very easily constructed.

The magic lantern was contrived, about the year 1650, by the celebrated Kircher, and is described in his work entitled, "Ars Magna Lucis et Umbræ."

There is, however, a curious account of phantom figures or demons, made to appear in the smoke of a fire and thrown upon walls, ascribed to Cellini, who lived nearly a century before Kircher. If the story be true, it would seem to show that phantasmagorial effects preceded the magic-lantern pictures, and that Cellini must have been acquainted with the construction of the instrument, or such effects as described could not have been produced. The magic lantern consists of a box provided with a chimney, containing a good lamp, or, still better, an oxy-hydrogen light; when the former is used, a reflector is usually

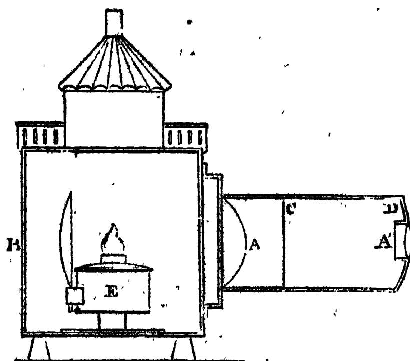


FIG. 70.—*Common Magic Lantern.*
B, the box; C, the lamp and reflector; A, the plano-convex lens; C C, the tube sliding within the first tube, and containing a double-convex lens, A'.

placed behind the flame, in order to increase the illumination of the pictures. The lime-light is placed behind the lenses called condensers (Fig. 71); these are usually composed of two plano-convex lenses, with the flat side placed towards the lamp, and the convex side touching, or nearly so, the convexity of the other lens, the flat side of which is towards the picture. The picture, painted or carefully photographed on glass, is placed in front of the condensers, and the whole projected and properly focused on a white screen by means of two other plano-convex lenses; the flat side of one lens being towards the picture, and the convex side towards the flat side of the second lens. The focusing lenses are contained in a tube which slides within the other, and is moved backwards and forwards with a simple rack-work.

The dissolving view arrangement, long kept a secret by Mr. Child, the inventor, is nothing more than two magic lanterns (Figs. 74, 75) placed side by side, and provided with sliding plates so arranged that, as one picture is gradually cut off, the second

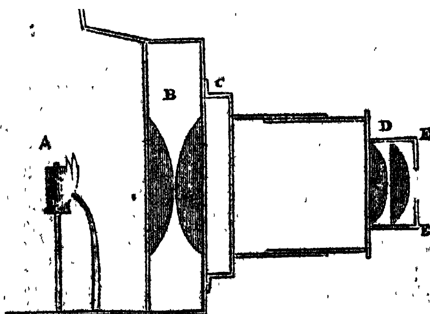


FIG. 71.—*Section of Superior Magic Lantern.*
A, oxy-hydrogen light; B, the condenser; C, the place to contain pictures; D, the focusing lenses; E E, the diaphragm to reduce the aberration of light.

is disclosed; and by alternately throwing on one picture and cutting off the other, the most pleasing effects are obtained, provided the two lanterns are precisely similar. To save gas, it is sometimes usual to turn off the oxygen from one lantern and to supply it to the other, and thus by alternately raising and lowering the lights in the lanterns the same result is obtained. (Fig. 76.)

The phantasmagorial effects first ascribed to Cellini are produced by painting in the figure-picture on glass, and then blackening out the whole of the ground, and—either by carrying the lantern and moving backwards and forwards behind the sheet, or by a mechanical arrangement in which the lantern runs on a tramway, and is focused as it approaches or recedes from the transparent disc—the pictures are made to increase or diminish at pleasure. In practice it is better to allow the lantern and person showing it to be carried on the same carriage, as the lever arrangement—shown in Fig. 72, and attached to the focusing lenses—is very apt to get out of order.

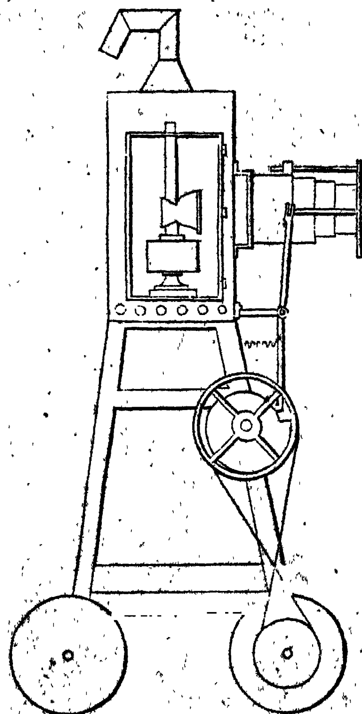


Fig. 72.

One of the most useful instruments for public exhibitions is that designed by Messrs. Chadburn, of 71 Lord Street, Liverpool, for the purpose of producing enlarged images upon a screen (similar to those of the magic lantern) from *opaque objects*, such as photographs, *carte de visites*, engravings, drawings, relievos, natural objects in all their colours, mechanical apparatus, or delicate mechanism in motion, such as the various parts of a watch or, still better, of a repeating watch. The instrument is simple in its construction, and consists of a lantern box, containing in the centre a pillar with adjusting screw, upon which the lime cylinder is placed; behind it the metallic reflector, which must be so adjusted that the picture is evenly illuminated. The reflector can be raised or lowered, or moved backwards and forwards; it receives the light, and throws it upon the condensing lens, by which it is concentrated upon the picture placed in the sliding door in the angular box joined to the square compartment. The light thrown off from the highly illuminated picture is received by the achromatic objective lenses (the focus of which is adjusted by the rack upon them), and projected upon the screen. The angular compartment may be removed, and replaced by a part with lenses for direct light and transparent pictures, as in the ordinary magic lantern.

An oyster directly after it is opened, the half of an orange, particularly if squeezed, as the effect is most ridiculous, the juice and pips appear to fall

upwards—all bodies being reversed in this instrument, the hand and orange are shown upside down—the human hand, the face of a watch, a gold or

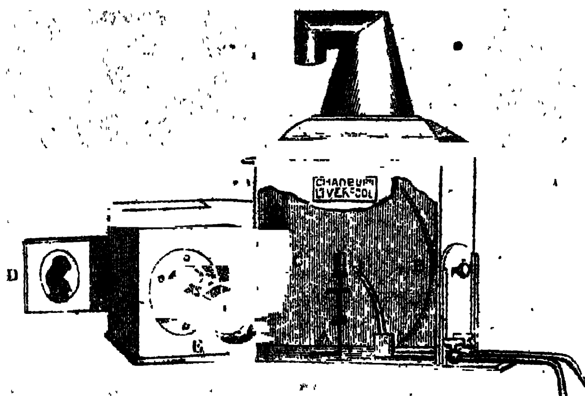


FIG. 73.—*Part Section and Elevation of Chadburn's Lantern.*
A, the light; B, reflector, C, condensing lens; D, the picture; E, the achromatic focusing lenses.

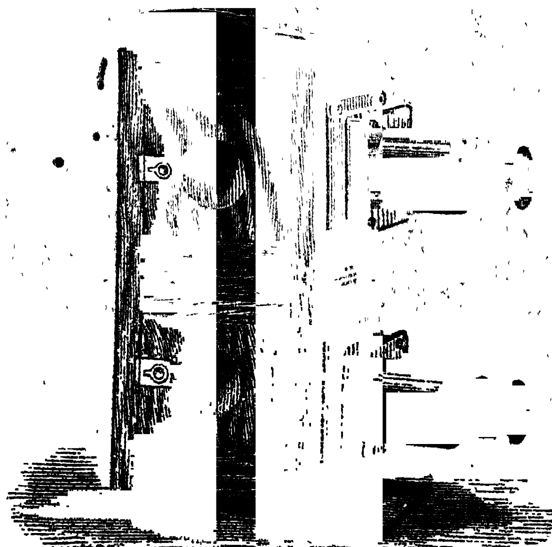


FIG. 74.—*Improved Dissolving View Apparatus by Highley,* 10 A *Great Portland Street.*

silver coin, and photographs of distinguished persons, are all good objects for this instrument.

In 1857 the writer introduced at the Polytechnic photographs of original

FIG. 75.—*Section of Highley's Dissolving View Apparatus* (Fig. 74).

drawings made by Mr. George Hine, the distinguished artist. The whole of the pictures illustrating the amusing story of Blue Beard were done in this

FIG. 76.—*Arrangement for saving oxygen gas, which is supplied alternately to one lime light and then to the other.*

way, and were most effective and successful, as every touch of the original artist is thus delineated in the photograph and subsequently thrown on the

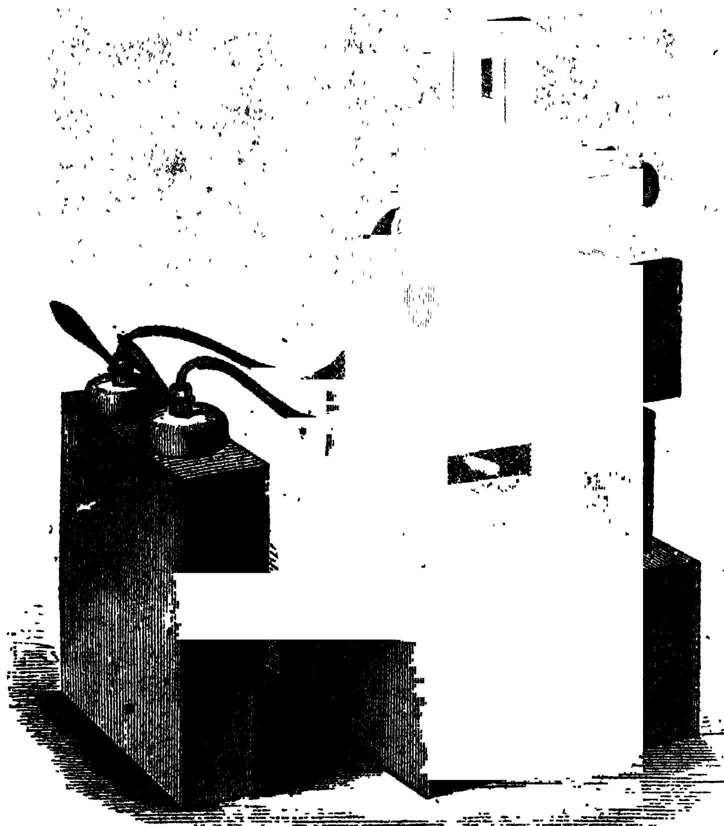


FIG. 77.—*Highley's complete Apparatus for Dissolving Views, all packed in two boxes.*

screen. Messrs. Negretti and Zambra followed up the idea by using photographs of statuary, which they displayed at Manchester with astonishing success, the Mechanics' Institution there realizing something like £600 by the exhibition in a few months. Mr. Highley has continued in the same track, and deserves notice for the admirable photographs of natural objects which he prepared for the dissolving-view apparatus—his arrangement of the latter contrivance, shown in Fig. 74 and in section Fig. 75, is good and convenient. The arrangement for saving oxygen gas (Fig. 76) is also extremely useful where the gas cannot be obtained easily. Portability and economy of space have all been carefully studied by Highley in Fig. 77, where the gases (oxygen or hydrogen) are condensed in separate strong copper cylinders which pack in one box, and the lantern, the slides, and the stand upon which they are placed, come out of and belong to the second box.

THE HUMAN EYE.

This elaborate and wonderful work of the Creator, built up of the usual constituents of animal substances, viz., albumen, gelatine, fibrine, with a little fatty matter, all marvellously shaped and fitted to their purposes, represents an optical instrument which transcends every contrivance made by the hand of man. The camera obscura is the nearest approach to an imitation of the eye. It is fitted with a double-convex lens; the rays of light thrown off from any object placed before the apparatus are brought to a focus, and received upon a sheet of paper or piece of ground glass. In the eye the same result is brought about by the refraction of light in the crystalline lens and the other humours; the rays are brought to a focus, and impinge upon a nerve, spread out as a delicate network to catch the beams, and to vibrate in sympathy with those exquisite undulations which cause the propagation of light, and thus to produce the sensation of vision. Anatomists have given this organ their most careful attention, and published elaborate drawings of the various parts of the eye. By the permission of Messrs. Chadburn, of Sheffield, a copy of their instructive diagrams of the eye is added (page 65).

A. The Pupil, or circular opening in the iris, capable of being contracted or enlarged, according to the amount and intensity of light.

B. The Iris, a flat circular membrane, of a grey, blue, or black colour, forming the anterior and posterior chambers of the eye. It performs the same functions as a diaphragm in an optical instrument.

C. The Sclerotic Coat, a tough white membrane, to which the muscles for moving the eyeball are attached.

D. The Eyelids, containing the tarsal fibro-cartilages.

E. The Cornea, composed of tough transparent laminæ, forming the front of the eye; the first surface, where the rays of light are refracted. Some anatomists have considered the sclerotica and cornea as one and the same, and have termed the cornea the transparent, and the sclerotica the opaque cornea.

F. The Aqueous Humour, contained in a delicate membrane filling the space from the cornea to the crystalline lens. The space occupied by this humour is divided into two parts by the iris, forming, as shown at B, the anterior and posterior chambers of the eye.

G. The Crystalline Lens, contained in a transparent membrane called the Capsule, the principal refracting medium of the eye. The capsule adheres by its edge to the ring-shaped body called the Ciliary Circle or ligament, N.

H. The Vitreous Humour, contained in the hyaloid membrane—a jelly-like substance, resembling the white of an egg, filling the body of the eye.

I. The Retina, a membrane which receives the impression of light, and transmits it to the brain through the optic nerve, K.

J. The Choroid Coat, a delicate membrane lining the sclerotica, covered on its inner surface with a black substance (*pigmentum nigrum*, resembling the colouring matter of the negro's skin) contiguous to the retina. The choroid, by its vascular tissue, serves to carry the blood into the interior of the eye.

K. The Optic Nerve.

L. Canal of Petit.

M. Central Artery of the optic nerve.

N. Ciliary Circle or ligament.

Fig.74

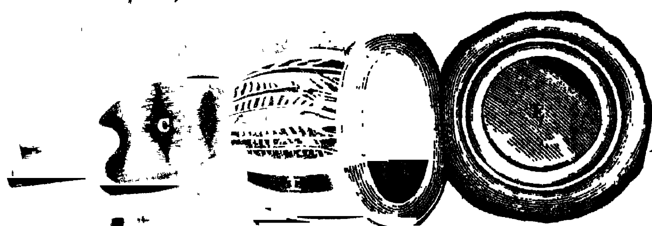


Fig.75

R
RS
D
B
E
F
L
Q
D
RS
R

Fig.76

FIG. 74.—*The Human Eye.* FIG. 75.—*The Eyeball, showing the Coats, &c. of the Eye.* FIG. 76.—*Longitudinal Section of the Eye and Orbit, through the dotted lines on Fig. 74.*

O. Ciliary Nerves.
P. *Vasa Vorticosa.*
Q. The Ciliary processes.
R. *Tunica Conjunctiva.*
R S. *Tunica Conjunctiva* collapsed, as when the eye is closed.
S. Elastic Muscle of the Eyelid.
T. Elastic Muscle of the Eye.
U. Superior Oblique Muscle.
V. Depressive Muscle of the Eye.
W. Section of Oblique inferior Muscle.
X. Nerves and Arteries.
Y. Tube conveying the optic nerve to the brain.
Z. Bone forming the socket of the eye.

N.B.—The same letters apply to each figure.

Brewster found the following to be the refractive powers of the different humours of the eye, the ray of light being incident upon them from air:

Aqueous humour . .	1·336	Crystalline lens, mean .	1·3839
Crystalline lens, surface	1·3767	Vitreous humour . .	1·3394
centre	1.3990	Water	1·3358

But the rays of light are not all incident upon them from the air, and as the rays refracted by the aqueous humour pass into the crystalline, and those from the crystalline into the vitreous humour, the indices of refraction of the separating surfaces of their humours will be—

From aqueous humour to outer coat of the crystalline .	1·0466
From " " to crystalline, using the mean index	1·0353
From vitreous to crystalline, outer coat	1·0445
From " to " using the mean index . .	1.0332

The eye, as already described, consists of four coats or membranes, which are disposed in the following order, viz., 1st, the sclerotic; 2nd, the cornea, which fits into it like the glass of a watch; 3rd, the choroid; and 4th, the retina; of two fluids or humours, the aqueous and the vitreous, and of a lens called the crystalline.

Over the cornea and sclerotic is expanded a delicate mucous membrane, called the conjunctiva. The iris is suspended across the eye, and in its centre is an opening, termed the pupil, which immediately opens when the light diminishes, and closes if the light is too strong. The posterior convexity of the lens is greater than the anterior. Sometimes, from a too great convexity of the lens or the cornea, the rays of light which enter the eye come to a focus before they impinge upon the retina, producing the defect called short-sighted vision. Optical science corrects this inconvenience by the use of a concave lens. If the crystalline lens is not sufficiently convex, the rays of light come to a focus behind the retina; this defect is surmounted by the use of a convex lens, which diminishes the divergence of the rays. Such ingenious artificial additions to the eye are common enough at the present day, but it may be asked, how did our forefathers bear these infirmities? Spectacles are supposed to have been unknown to the ancients, and it is stated by Francisco Redi that they were invented in the 13th century, between the years 1280 and 1311, probably about the year 1299 or 1300; he gave the honour of the discovery to

Alexander de Spina, a monk of the order of Predicants of St. Catharine, at Pisa. Muschenbroek, the old electrician who discovered the Leyden jar, observes that it is inscribed on the tomb of Salvinus Armatus, a nobleman of Florence, who died in 1317, that he was the inventor of spectacles. This may have been the person who had the secret as well as the learned monk, because Redi states that the latter only disclosed the secret upon learning that another person had it as well as himself.

Mr. Acland makes the following practical and valuable observations on defects of vision:

"*On the Symptoms indicating a Necessity for Spectacles.*

"The natural decay of vision occurs usually from thirty to fifty years of age, varying according to habits and employment of the individual. Sometime during this interval the refractive power of the crystalline humours of the eye slightly alters its condition, whilst the crystalline lens and cornea change their form, so that a difficulty of distinct vision is felt. The eye loses a portion of its power of seeing at varying distances, or its power of adjustment; and near objects are no longer as easily seen as in youth. Reading small print by candle-light is difficult, as the book requires to be held at a greater distance from the eye than formerly, and a more powerful light is needed; and even then the letters appear misty, and to run one into the other, or seem double. And still further, in order to see more easily, the light is often placed between the book and the eye, and fatigue is soon felt, even with moderate reading.

"When these symptoms show the eye to have altered its primitive form, spectacles are absolutely needed. Nature is calling for aid, and must have assistance, and if such is longer withheld, the eye is needlessly taxed, and the change, which at first was slight, proceeds more rapidly, until a permanent injury is produced.

"There is a common notion that the use of spectacles should be put off as long as possible, but such is a great mistake, leading often to impaired vision for life, and is even more injurious than a too early employment.

"Timely assistance relieves the eye, and diminishes the tendency to flattening, whereas should the use of spectacles be longer postponed, the eye changes rapidly, and when the optician is at last consulted, it is found that a deeper focus spectacle must be used than usual for the first pair, and even these suit but a short time, and have to be again exchanged for those of still deeper power; and these frequent changes become a matter of necessity which, unless judiciously checked, continue during life.

"It must not be forgotten that, when first using spectacles, they are not required during daylight, but only for reading, &c., by artificial light, and it may be from six months to two years from the time of first adopting them ere they will be required for day use.

"*Spectacles for the Short-sighted.*—Short sight is often present at birth, but is little noticed, nor its inconveniences felt, until study becomes imperative. When this occurs, the power employed should be always slightly under that needed to remedy the defect, otherwise the eye will gradually accommodate itself to the lenses, and require constantly an increase of power. In all cases leave some little for the adjustment of the eye to do, and then you may, after a time, diminish the power of the lenses needed.

"*The Optician's Knowledge.*—Having now shown when spectacles should be employed, let us for a moment consider what are the requirements that

should in all cases be possessed by the optician to whom the selection of spectacle lenses is entrusted.

"These requirements are—

"1st. An intimate knowledge of the anatomical structure of the eye, and of the theory of vision.

"2nd. An extensive acquaintance with the science of optics.

"3rd. A sound mathematical knowledge.

"4th. A practical acquaintance with the manufacture of lenses and spectacle frames.

"Having for the last fourteen years made the adaptation of spectacles my especial study, at the establishment of Messrs. Horne and Thornthwaite, 122, Newgate Street, I have frequently met with cases where great injury has been done to the weak-sighted by the ordinary optician's improper selection of spectacles; and I could heartily wish more of my medical brethren would bring their knowledge to bear on this subject,—which demands, and frequently calls forth, all the science and skill we possess, to meet the requirements of some abnormal cases that present themselves."

The knowledge which the eye conveys to the mind is boundless; the relative condition of matter, large and small, of motion or rest, of colour, of solidity, of transparency, of brilliancy, of opacity, of space or distance, are only a few of the results attained by the exercise of the faculty of vision.

THE STEREOSCOPE.

This most valuable and instructive instrument, and now not only a "household word," but a piece of domestic apparatus without which no drawing-room is thought complete, was invented by Professor Wheatstone, and subsequently modified by Sir D. Brewster. It demonstrates that man must have two eyes in order to enjoy the appreciation of distance, or, like the fabled Polyphemus, we might only have had one eye. Mr. Woodward gives the following excellent and familiar explanation of the phenomena produced by the stereoscope.

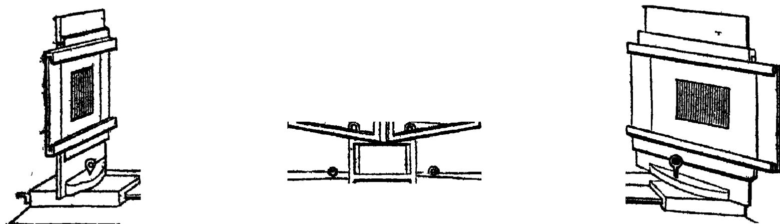


FIG. 77.

PROFESSOR WHEATSTONE'S REFLECTING STEREOSCOPE.

A familiar explanation of the phenomena produced by the Stereoscope.

"The name is derived from two Greek words, signifying to view solid things, and the instrument is so constructed that two flat pictures, taken under certain conditions, shall appear to form a single solid or projecting body.

"A picture of any object is formed on the retina of each eye; but although there may be but one object presented to the two eyes, the pictures formed on the two retinæ are not precisely alike, because the object is not observed from the same point of view.

"If the right hand be held at right angles to, and a few inches from, the face, the back of the hand will be seen when viewed by the right eye only, and the palm of the hand when viewed by the left eye only; hence the images formed on the retinæ of the two eyes must differ, the one including more of the right side and the other more of the left side of the same solid or projecting object. Again, if we bend a card so as to represent a triangular roof, place it on the table with the gable end towards the eyes, and look at it, first with one eye and then with the other, quickly and alternately opening and closing one of the eyes, the card will appear to move from side to side, because it will be seen by each eye under a different angle of vision. If we look at the card with the left eye only, the whole of the left side of the card will be plainly seen, while the right side will be thrown into shadow. If we next look at the same card with the right eye only, the whole of the right side of the card will be distinctly visible, while the left side will be thrown into shadow; and thus *two* images of the *same* object, with *differences of outline, light and shade*, will be formed—the one on the retina of the right eye, and the other on the retina of the left. These images falling on *corresponding parts of the retinæ* convey to the mind the impression of a *single object;** while experience having taught us, however unconscious the mind may be of the existence of two different images, that the effect observed is always produced by a body which really stands out or projects, the judgment naturally determines the object to be a projecting body.

"It is experience also that teaches us to judge of distances by the different angles of vision under which an object is observed by the two eyes; for the inclination of the optic axes, when so adjusted that the images may fall on *corresponding parts of the retinæ*, and thus convey to the mind the impression of a single object, must be greater or less, according to the distance of the object from the eyes.

"Perfect vision cannot then be obtained without two eyes, as it is by the combined effect of the image produced on the retina of each eye, and the different angles under which objects are observed, that a judgment is formed respecting their solidity and distances.

"A man restored to sight by couching cannot tell the form of a body without touching it, until his judgment has been matured by experience, although a perfect image may be formed on the retina of each eye. A man with only one eye cannot readily distinguish the form of a body which he had never previously seen, but quickly and unwittingly moves his head from side to side, so that his one eye may alternately occupy the different positions of a right and a left eye; and, if *we approach a candle with one eye shut*, and then attempt to snuff it, we shall experience more difficulty than we might have expected, because the usual mode of determining the correct distance is wanting.

"In order, then, to deceive the judgment, so that flat surfaces may represent

* That this is the correct theory of single vision with the two eyes is evident. For if, while looking at a single object with both eyes, we make a slight pressure with the finger on one of the eyeballs, we shall immediately perceive two objects; but, on removing the pressure, only one will be again seen.

solid or projecting figures, we must cause the different images of a body, as observed by the two eyes, to be depicted on the respective retinæ, and yet to appear to have emanated from one and the same object. Two pictures are therefore taken from the really projecting or solid body, the one as observed by the right eye only, and the other as seen by the left. These pictures are then placed in the box of the stereoscope, which is furnished with two eye-pieces, containing lenses so constructed that the rays proceeding from the respective pictures to the corresponding eye-pieces shall be refracted or bent outwards, at such an angle as each set of rays would have formed had they proceeded from a single picture in the centre of the box to the respective eyes, without the intervention of the lenses; and as it is an axiom in optics that the mind always refers the situation of an object to the direction from which the rays appear to have proceeded when they enter the eyes, both pictures will appear to have emanated from one central object; but as one picture represents the real or projecting object as seen by the right eye, and the other as observed by the left, though appearing by refraction to have proceeded from one and the same object, the effects conveyed to the mind, and the judgment formed thereon, will be precisely the same as if the images were both derived from *one solid or projecting body*, instead of from *two pictures*, because all the usual conditions are fulfilled; and consequently the two pictures will appear to be converted into one solid body.

"The necessary pictures for producing these effects, excepting those of geometrical figures, which may be laid down by certain rules, cannot, however, be drawn by the hands of man; for, as Professor Wheatstone has observed, 'It is evidently impossible for the most accurate and accomplished artist to delineate, by the sole aid of his eye, the two projections necessary to form the stereoscopic relief of objects as they exist in nature, with their delicate differences of outline, light, and shade. But what the hand of the artist was unable to accomplish, the chemical action of light, directed by the camera, has enabled us to effect.'

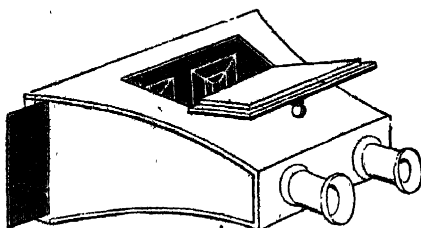


FIG. 78.—*Brewster's Refracting Stereoscope.*

"Daguerreotype portraits and Talbotype pictures are therefore taken, usually, by two cameras placed towards the object, with a difference of angle equal to the difference of the angle of vision of the two eyes, which is about 18° when the object is eight inches from the eyes; hence, if these be carefully examined and compared with the original projecting objects, they will be found to be faithful representations of the object as seen by each eye respectively."

DIRECTIONS FOR USING THE STEREOSCOPE.

"The objects must be so adjusted in the box, that only one picture may be seen in the centre, care being taken that the pictures are not reversed so as to be seen by the right eye instead of the left, and *vice versâ*.

"The proper position of portraits, buildings, and similar objects cannot be mistaken; but where this is not readily perceived, it should be ascertained, when the object can be marked so as at once to be properly placed.

"The eye-pieces, if allowed to turn, are marked with arrows, to indicate their proper position, these must be placed inwards, and in a right line with each other.

"The eye-pieces in some instances are made to draw out to suit the foci of different persons. But those who use spectacles will generally see best with them on, bringing them forward *so as to lie flat on the eye-pieces*, which in such cases should not be drawn out.

"Persons, however, with a defective sight in either eye will not be able to perceive the astonishing effects of the arrangement, as *two different images* will not be perfectly formed on the retinæ of the respective eyes."



FIG. 79.—*Example of the zigzag path of Lightning.*

PERSISTENCE OF VISION.

There is a most interesting class of experiments that depend chiefly upon another property or faculty of vision, by which we retain for a certain limited period the images of objects presented before us. It may be premised that the term *image* refers to that picture which remains upon the eye as long as the object is present; whereas the *spectrum*, which every one knows is the Latin for spectre, is that lingering impression left upon the eye after the real object has been removed. This property, like binocular vision, may be satisfactorily proved in various ways. Thus, if a broom-stick be thrust into the fire and burnt, so as to obtain a mass of ignited charcoal, and then whirled rapidly round in a circle, a complete circle of light is visible. Now,

it is evident that the hand or stick cannot be in every part of the circle at the same instant of time; the mind is therefore obliged to confess, in tracing the stick through the quarter, half, three-quarter, and whole circle, that of course the impression of the train of light must have remained upon the eyes, or else a single spot of light moving in a circle could only have been visible. A planet, if it moved fast enough, would leave a train of light, indicating, like the burning stick, its particular path or disc. The meteors move with such amazing velocity that their trains of light are extremely vivid, marked, and lengthened out, and show distinctly the direction or path they take. A discharge of natural electricity or lightning would, if it moved slowly, be represented by a ball of fire travelling from one point to another; it is, however, usually represented by a lengthened-out zigzag. (Fig. 79.) It is then called "forked lightning," and every part of its track remaining impressed on the vision, the whole appears as a series of continuous lines of fire, which, although diverted right or left, in a horizontal, perpendicular, or angular direction, pursue their path to the point where the discharge occurs, they are visible as a whole, and called a flash of lightning.

The act of winking the eye is another familiar example of the same truth; the eyelid closes and re-opens so rapidly, for the purpose of lubricating the eyeball, that the object we may be looking at does not become invisible, but remains impressed upon the eye. It has been ascertained that the impression lasts for about the seventh or eighth part of a second, and although sometimes it may last for the third part of a second, it depends, no doubt, upon the amount of sensitiveness belonging to the organ of vision. There are very curious modifications of this property of vision, whereby colours and their complementary tints are impressed upon the eye. Thus, if a red wafer is placed on a sheet of black paper, and well illuminated by a sunbeam or any brilliant light, it will appear again to a spectator looking from the black to a white paper as a green one; the red wafer being the real *image*, whilst the green one is the *spectrum*. The experiment may be varied with a yellow wafer on a black ground, which appears violet when the eyes are turned rapidly away to a white surface. On this principle a very entertaining book has been published. The reader, after staring at one of the illustrations, is directed to look up to the ceiling or wall, to observe the spectral effect. Sir D. Brewster explains these curious results, spoken of as accidental colours, by supposing that the eyes, after staring at any particular colour, say a bright red, become so fatigued or partially paralyzed that they cannot receive or appreciate the wave of red light, but as white light is made up of various waves of coloured light, the remaining sets of waves—viz., blue or yellow—can impress the vision by producing the complementary green colour. The late Dr. Golding Bird describes the following mode of demonstrating this fact, giving the merit of the experiment to the late Professor Cowper, who invented so many clever illustrations:

"Cut in a piece of cardboard a series of holes, so that when folded together they will exactly correspond, the whole resembling open lattice-work. Provide some sheets of thin tissue-paper of various colours, selecting those presenting strongly-defined tints; place one of them between the folds of the cardboard and hold it up to a vivid light, keeping the eye fixed on the lattice-work whilst the light penetrates the coloured paper; in a few seconds the white colour of the pasteboard will vanish, and be replaced by a strongly marked tint complementary to that of the paper placed in it. Thus, with

yellow paper the framework will appear violet, with blue it will be orange, and with red it will be green. This illusion is so complete that it always excites surprise in those who see it for the first time."

A little gunpowder placed on a block of wood, with iron filings sprinkled over it, throws up a shower of brilliant sparks of burning particles of iron when fire is applied; and if the experiment is performed in a dark room, and the eyes of those standing near the experiment are closed directly after witnessing the real image of the burning particles of metal, they will see a volume of faint light, sometimes coloured, which remains upon the retinæ, and forms a spectral image. If the colours of the solar spectrum are painted



FIG. 80.—*The Polytechnic Phenakistiscope.*

on a glass disc, to which rapid motion may be imparted, after being fitted into the oxy-hydrogen lantern, a large disc can be thrown upon the screen, which changes to a greyish white directly it is set in motion. The change of the disc of many colours to a grey is very impressive, and is probably understood better by suggesting that the spectator should look through an aperture made in some opaque screen at the coloured disc; the red, orange, yellow, green, blue, indigo, and violet pass before the aperture with such rapidity that they have not time to impress the retina as single colours, succeeding each other one by one, and they must therefore act collectively on the vision; if collectively, then synthetically; or, in plainer terms, the colours are caused to unite and reconstitute white light, or the nearest approach to it that can be produced by a mechanical contrivance of this nature.

Many years ago the juveniles discovered that by twirling a halfpenny you could see both sides of it; not only the portrait of the reigning monarch, but the usual figure of Britannia. This simple arrangement appears to have been succeeded by a more elegant contrivance, invented by the late Dr.

Paris, and called the Thaumatrope, or "Wonder-Turner," like many other clever things, a "nine days' wonder," and succeeded and surpassed by a very ingenious optical toy, invented by Plateau, called the Phenakistiscope.

In connection with the name of Plateau, the Rev. Mr. Shaw, in a letter to the writer, says: "It may enhance the interest connected with the Phenakistiscope, if not known to you or your auditory, to learn that this gentleman, now residing in Ghent, Belgium, is and has been for years totally blind, carrying out his discoveries and observations entirely through the intervention of his wife. I mention this from personal experience, having assisted him some years ago to translate a treatise on capillary attraction for English publication." Plateau's instrument, as arranged for the oxy-hydrogen light by Soleil Duboscq, is a very complicated affair, consisting of the usual condensing lenses, in front of which is the disc of glass with devices in regular order painted upon it. The latter, of course, rotates, and at the same time another wheel, containing four double-convex lenses set in the four quarters of the wheel, supplies that intermittent and separate light to each picture, which, when focused by the front lenses, produces all the effects of the popular Zoetrope (Fig. 81).

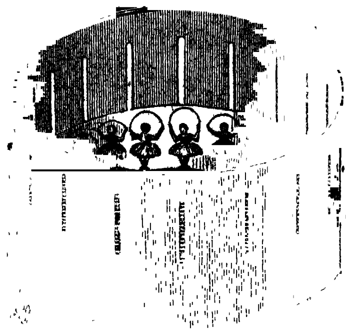


FIG. 81.—*The Zoetrope at rest, showing the simple construction of the Instrument.*

In order to produce the best effect, it is absolutely necessary that each picture should be impressed separately but quickly upon the vision; and this is secured by the apertures followed by a certain opaque space, as employed in Plateau's original device so long exhibited at the Polytechnic. This old-fashioned apparatus consists of a wheel perforated with apertures, on the back of which the figures are painted, and when the spectator looks through the slits into a plane mirror the figures appear to move.

If the figures are painted in the usual manner on a disc, they all merge one into the other when the disc is set in motion, and a series of circles and eccentrics alone become apparent, which do not afford the slightest idea that they represent the figures; but Sir Charles Wheatstone has shown that by constantly checking the motion, by a peculiar mechanism, so that each separate figure is impressed momentarily on the vision, then the same effects of motion are obtained without the intervention of the usual revolving slits or

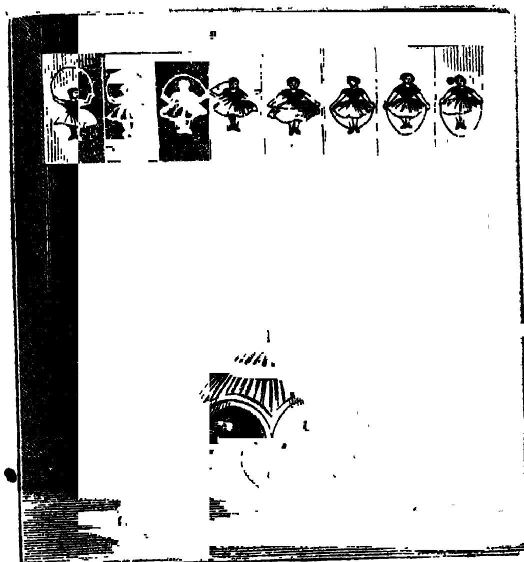


FIG. 82.—*The Zoetrope in motion, simulating exactly the motions of a little girl playing with a skipping-rope.*

apertures. This important experiment establishes the basis of this class of illusions; and the fact is further proved by the penny book now sold in the streets. The little pages have printed on them a series of devices representing any ordinary act of motion, such as a see-saw, and by rapidly passing the pages over the thumb with the first finger the effect of apparent movement is secured, as it would be with Plateau's apparatus, the Zoetrope, or Wheatstone's disc, with the checking and arresting mechanism.

The best apparatus for showing to a large audience all the effects of persistence of vision, and the curious and elaborate movements obtainable from painted discs, is undoubtedly that devised by Mr. Thomas Rose, of Glasgow.* But before explaining this contrivance it will be advisable to study Faraday's paper.

One of the first and most interesting papers written on the effects which are produced by persistence of vision is that of the late Dr. Faraday, and entitled, "On a Peculiar Class of Optical Deceptions;" and, as the apparatus used chiefly consists of models constructed in cardboard, some copious quotations from that paper are here made.†

"The preeminent importance of the eye as an organ of perception confers an interest upon the various modes in which it performs its office, the circumstances which modify its indications, and the deceptions to which it is liable, far beyond what they otherwise would possess. The following account of a

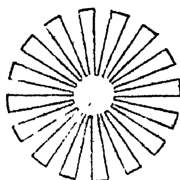
* Fully described in article "Persistence" in a new edition of the "Popular Encyclopædia." Blackie and Sons, London, Glasgow, and Edinburgh. † "Journal of the Royal Institution." vol. i, p. 205.

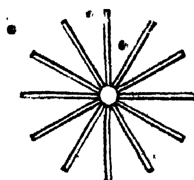
peculiar ocular deception, which, in a greater or smaller degree, is not uncommon, and which, if looked for, may be observed with the utmost facility, may therefore prove worthy of attention; and I am the more inclined to hope so, because in some points it associates with an account and explanation of an ocular deception given by Dr. Roget in the 'Philosophical Transactions' for 1825, page 121.

"The following are some cases of the appearance in question. Being at the magnificent lead-mills of Messrs. Maltby, two cog-wheels were shown me moving with such velocity that if the eye were retained immovable no distinct appearance of the cogs in either could be observed; but, upon standing in such a position that one wheel appeared behind the other, there was immediately the distinct, though shadowy, resemblance of cogs moving slowly in one direction.

"Mr. Brunel, junior, described to me two small similar wheels at the Thames Tunnel; an endless rope, which passed over and was carried by one of them, immediately returned and passed in the opposite direction over the other, and consequently moved the two wheels in opposite directions with great but equal velocities. When looked at from a particular position, they presented the appearance of a wheel with immovable radii.

"When the two wheels of a gig or carriage in motion are looked at from an oblique position, so that the line of sight crosses the axle, the space through which the wheels overlap appears to be divided into a number of fixed curved lines, passing from the axle of one wheel to the axle of the other, in form and arrangement resembling the lines described by iron filings between the opposite poles of a magnet. The effect may be obtained at pleasure by cutting two equal wheels out of white cardboard (Fig. 83 or 84), each having from twelve


FIG. 83.


FIG. 84.

to twenty or thirty radii, sticking them on a large needle two or three inches apart, revolving them between the fingers, and looking at them in the right direction against a dark or black ground: the greater the velocity of the wheels, the more perfect will be the appearance. (Fig. 85.)


FIG. 85.

"When the dark-coloured wheel of a carriage is moving on a good light-coloured road, so that the sun shines almost directly on its broadside, and the wheel and its shadow are looked at obliquely, so that the one overlaps the other in part, then in the overlapping part luminous or light lines will be perceived, curved more or less, and conjoining the axle and its shadow, if the wheel and shadow are superposed sufficiently, or tending to do so if they

are superposed only in part. The more rapid the motion, the more perfect is the appearance. The effect may be easily observed (Fig. 86) by making a pasteboard wheel like one of those just described, blackening it, sticking it on a pin, and revolving it in the sunshine or candle-light before a sheet of white paper.



FIG. 86.

"If the wheel be converted into a teetotum or top, by having a pin thrust through its centre and spun upon a sheet of white paper, the effect produced by the wheel and its shadow will be obtained with facility, and in form will resemble Fig. 85. In all these cases no rims are required; the spokes or radii will produce the effect. If a carriage wheel running rapidly before upright bars, as a palisade or railing, be observed, the attention being fixed on the wheel, peculiar stationary lines will appear; those perpendicular to the nave or axis will be straight, but the others curved; and the curve will be greatest in those which are furthest from the upper straight line. These curves are the same in form as those already described and explained by Dr. Roget,* and the appearance itself is produced in a similar manner; but the phenomena are distinct, and the causes different. The effect at present referred to is best observed when the velocities are great, whereas that explained by Dr. Roget takes place only when the velocities are moderate. It is probable that the effects briefly mentioned by an anonymous writer in the 'Quarterly Journal of Science,' first series, vol. x., p. 282, and already referred to by Dr. Roget, were of the kind now to be explained; for, though the description is not accurate, either for the effects which form the object of this paper or that explained by Dr. Roget, and is, indeed, inconsistent with the observation or explanation of any of the phenomena, it probably had its origin in the occurrence of some of both kinds under the eyes of the writer.

"The effect is easily obtained by revolving a white pasteboard wheel before a black or dark ground, and then, whilst regarding the wheel fixedly, traversing the space before it with a grate also cut out of white pasteboard. By altering the position of the grate and direction of its motion, it will be seen that the straight lines in the wheel are always parallel to the bars of the grate, and that the convexity of the curved lines is always towards that side of the grate where its motion coincides in direction with the motion of the radii of the wheel. By varying the velocity of the wheel and grate, the curves change in their appearance, and the whole or any part of the system, as described and figured by Dr. Roget, may be obtained at pleasure.

"I have had a very simple apparatus constructed by which these and many other analogous appearances may be shown in great perfection and variety. One board was fixed upright upon the middle of another, serving as a base; the upright board was cut into the shape represented in Fig. 87; the middle and two extreme projections, forming points of support, were supplied with little caps cut out of copper plate and bent into shape (Fig. 88), so that, when in their places, they offer four bearings for the support of two axes, one on each side the middle. The axes are small pieces of steel wire tapered at the extremities; each has upon it a little roller or disc of soft wood, which, though it

* "Philosophical Transactions," 1825, p. 131.

can be moved by force from one part of the axis to another, still has friction sufficient to carry the latter with it when turned round. These axes are made to revolve in the following manner: a circular copper plate, about 4 in. in diameter, has three pulleys of different diameters fixed upon its upper surface, whilst its lower surface is covered with a piece of fine sand-paper, attached by cement. A hole is made through the centre of the plates and pulleys, and guarded by a brass tube, so fitted as to move steadily but freely upon an upright steel pin fixed in the middle of the centre wooden support; hence, when the plate is in its place, it rests upon the two rollers belonging to the horizontal axes, whilst it is rendered steady by the upright pin. It can be easily turned round in a horizontal plane, and it then causes the two axes with their rollers to revolve in opposite directions; and the velocities of these can be made either equal to each other, or to differ in almost any ratio, by shifting the rollers upon the horizontal axes nearer to or farther from the centre of the stand.

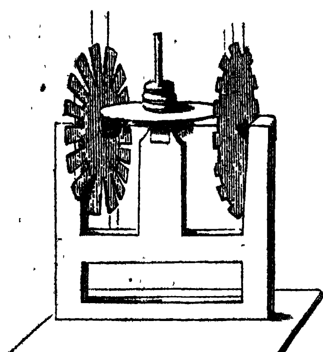


FIG. 87.

"To produce motions of the axes in the same direction, an aperture was cut in the lower part of the upright board; a roller turned for it, which loosely fitted within the aperture; a steel pin or rod passed as an axis through the roller. The roller hangs in its place by endless lines made of thread, passing under it and over little pulleys fixed on the horizontal axis. When, therefore, it is turned by the projecting pin, it causes the revolution of the axes. The variation in velocities is obtained by having the roller of different diameters in different parts, and by having pulleys of different dimensions. This description will be easily understood by reference to the figures 87 and 88.



FIG. 88.

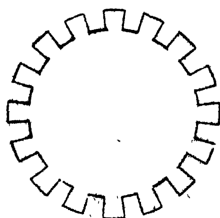


FIG. 89.

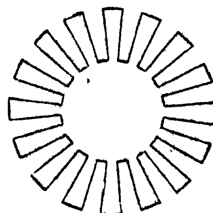


FIG. 90.

"This apparatus had to carry wheels, either with cogs or spokes, which was contrived in the following manner:—The wheels were cut out of cardboard, were about 7 in. in diameter, and were formed with cogs and spokes at pleasure.

A piece of cork, being the end of a phial cork, about the tenth of an inch in thickness, was then fastened by a little soft cement to the middle of the wheel, and a needle run through both and then withdrawn. These wheels could at any time be put upon the axes, and, being held sufficiently firm by the friction of the cork, turned with them. By these arrangements the axes could be changed, or the wheels shifted, or the velocities altered without the least delay.

"The beauty of many of the effects obtained by this apparatus has induced me to describe it more particularly than I otherwise should have done. The appearance which I first had shown to me by Mr. Maltby was exhibited very perfectly: two equal cog-wheels were mounted (Fig. 89) so as to have equal opposite velocities; when put into motion, which is easily done by the thumb and finger applied to the upper pulley and the horizontal copper plate, they presented each the appearance of an uniform tint at the part corresponding to the series of cogs or teeth, provided that the eye was so placed as to see the whole of both wheels; but when a position was taken up so that the wheels were visually superposed, then, in place of an uniform tint, the appearance of teeth or cogs were seen, misty, but perfectly stationary, whatever the degree of velocity given to the wheel. By cutting the cogs or teeth in the wheel nearest to the eye deeper (Fig. 90), the eye could be brought into the prolongation of the axes of the wheels, and then the spectral cog-wheel appeared perfect (Fig. 91). The number of intervals thus occurring was exactly double the number of teeth in either wheel; thus a wheel with twelve teeth produced twenty-four black and twenty-four white alternations. When one wheel was made to move a little faster than the other, by shifting the wooden roller on its axis, then the spectrum travelled in the direction of that wheel having the greatest velocity, and with more rapidity the greater the difference between the velocities of the two wheels. When the wheels were looked at so that they only partly visually superposed each other, the effect took place only in those parts; and it was striking and extraordinary to observe, as it were, two uniform tints mingling and instantly breaking out into the alternations of light and shade which I have described. There are many variations in the curvature and other appearances obtained by altering the position of the eye, which will be immediately understood when observed, and which, for brevity's sake, I refrain from describing.

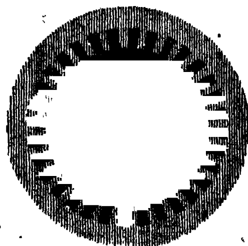


FIG. 91.

"Wheels were then fixed on the machine, consisting of radii or spokes, each having twelve, equal in length and width (Fig. 84). When revolving alone, each wheel gave with a certain velocity a perfectly uniform tint; but when visually superposed there appeared a fixed wheel, having twenty-four spokes, equal in dimensions to the original spokes. Variations of the position of the eye, or of the relative velocity of the two wheels, caused alternations similar to those I have referred to with the cog-wheels.

"In observing these effects, either the wheels should be black or in shade, whilst the part beyond is illuminated; or else the wheels should be white and enlightened, whilst the part beyond is in deep shade. The cog-wheels present nearly a similar appearance in both cases, though in reality the parts of the spectrum which appear darkest by one method are lightest by the other.* The

spoke-wheels give a spectrum having white radii in the first method, and dark radii in the second. Placing the wheels between the eye and the clouds, on a white wall, or a lunar lamp, answers very well for the first method; and, for the second, merely reversing the position, and allowing the light to shine on the parts of the wheel towards the eye, whilst the background is black or in obscurity, is all that is required. Strictly, the phenomena should be viewed with one eye only, but it is not often that vision with two eyes disturbs the effects to any extent.

"The cause of these appearances, when pointed out, is sufficiently obvious, and immediately indicates many other effects of a similar kind, and equally striking, which are dependent upon it. The eye has the power, as is well known, of retaining visual impressions for a sensible period of time; and in this way recurring actions, made sufficiently near to each other, are perceptibly connected and made to appear as a continued impression. The luminous circle visible when a lighted coal or taper is whirled round, the beautiful appearance of the Kaleidophone, the uniform tint spread by the revolution of one of the spoke or cog wheels already described, are few of the many effects of this kind which are well known.

"But during such impressions the eye, although to the mind occupied by an object, is still open, for a large proportion of time, to receive impressions from other sources; for the original object looked at is not in the way to act as a screen, and shut out all else from sight. The result is that two or more objects may seem to exist before the eye at once, being visually superposed. The school-boy experiment of seeing both sides of a whirling halfpenny at the same moment, the appearance of the Thaumatrope, and the transparency of the revolving cog or spoke wheels referred to—in consequence of which other objects are seen through the shaded parts—are all effects of this kind; two or more distinct impressions, or sets of impressions, being made upon the eye, but appearing to the perception as one.

"So it is in the appearances particularly referred to in this paper. They are the natural results of two or more impressions upon the eye, really, but not sensibly, distinct from each other. If, whilst the eye is stationary, a series of cogs, like those represented by the continuous outline (Fig. 92), pass rapidly before it, they produce a uniform tint to the eye; and, for the purpose of following out the description, let it be supposed the cogs are in shade between the eye and a white background, the tint is then a hazy semi-transparent grey. If another series of cogs, represented by the dotted outline, and close to the first, so as to give no sensible angular difference to the dimensions of the cogs, pass with equal velocity in the same direction, it will produce its corresponding tint. If the two sets of cogs be visually superposed in part, as in the figure, there will be no alteration in the uniformity of the tint. If the cogs of one set be more or less to the right or left of the other, then the superposed part will approach more or less to the tint of the shaded and uncut part of the card-board wheel, and be less transparent. But if, instead of the motion being equal, the velocities are unequal, then total changes of the appearance supervene; the spectrum (if I may so call it) of the superposed parts becomes alter-

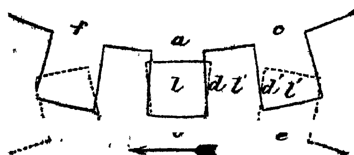


FIG. 92.

nately light and dark, and the alternations take place more or less rapidly as the velocities of the two sets of cogs differ more or less from each other.

"When the cogs move in opposite directions, the uniform tint which each alone can produce is soon broken up in the superposed parts into lighter and darker portions; and when the velocities of both are equal, the spectrum is resolved into a certain number of light and dark alternations, which are perfectly fixed, and which to the mind offer a singular contrast to the rapidly moving state of the wheels, and to the variations which their velocity may undergo without altering the visible result.

"The effect, strange as it at first appears, will be easily understood by reference to Fig. 91. Suppose the eye directed to the part *l* beyond the cogs, and the sets of cogs to be moving with equal velocities in opposite directions, indicated by the arrow-heads, the part *l* will be eclipsed by the cogs *a* and *b* simultaneously, and for exactly the same time; for they begin to cover it and leave it together. *l*, therefore, is alternately open to and shut from the eye for equal times; for what these cogs have done will be performed by all the other cogs in turn, and the cogs are equal in area to the spaces between;

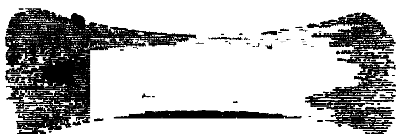


FIG. 92 A.



FIG. 92, B.

half the light, therefore, from that part of the background comes to the eye, and produces a corresponding impression. But with respect to the point *d*, although the cog *b* is just leaving it exposed, the cog *a* is just beginning to eclipse it; and by the time the latter has passed over, the edge of the cog *e* will be upon the spot, and that cog will therefore hide it until *f* comes up, so that in fact the point *d* is always hidden; no light comes from that part of the background, and it consequently appears dark. *l'* is circumstanced just as *l* was, for the cogs *a* and *e* cover it simultaneously, and so do all the other cogs in pairs; it is, therefore, a light space in the spectrum. *d'* is a repetition in everything of *d*, and is a dark space. The parts intermediate between the maxima of light and darkness will, by examination, be found to be eclipsed for intermediate periods, and to appear more or less dark in consequence, so that the appearance of the spectrum belonging to the visually superposed parts of the two sets of cogs is as in Fig. 92 A.

"In the case of equal wheels with radii, the fixed spectrum produced when the wheels superpose each other has twice the number of radii of either wheel, that being, of course, the number of times which the radii coincide with each other in one revolution.

"Fig. 92 B represents the fixed spectrum produced by two equal wheels of eight radii each. When the radii or spokes are narrow, the difference in the intensity of tint between the middle and the edges of each image of a spoke is so slight as to be scarcely perceptible. But as this circumstance and many others will explain themselves immediately they are experimentally observed,

it is unnecessary to dwell minutely upon them here. A very simple experiment will render the whole of these effects perfectly intelligible.

"If a little rod of white cardboard, five or six inches long, and one-thirtieth of an inch wide, be moved to and fro from right to left before the eye, an obscure or black background being beyond, it will spread a tint, as it were, over the space through which it moves. (Fig. 93, A.) A similar rod held and moved in the other hand will produce the same effect; but if these be visually superposed, *i.e.*, if one be moved to and fro behind the other, also moving, then in the quadrangular space included within the intersection of the two tints will be seen a black line, sometimes straight, and connecting the opposite angles of the quadrangle, at other times oval or round, or even square, according to the motions given to the two cardboard rods (Fig. 94, B).

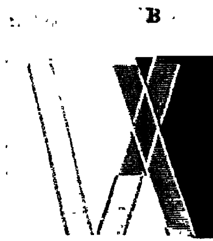


FIG. 93.

"This appearance is visible even when the rods are several inches or a foot apart from each other, provided they are visually superposed. It is produced exactly as in the former case, and the black line is in fact the path of the intersecting point of the moving rods. As their motions vary, so does the course of this point change, and, wherever it occurs, there is less eclipse of the background beyond than in the other parts, and consequently less light from that spot to the eye than from the other portions of the compound spectrum produced by the moving rods.

"In this experiment the eye should be fixed, and the part looked at should be between the planes in which the rods are moved. The variation produced by using black rods, and looking at a white ground, will suggest itself. Those who find it difficult to observe the effect at first, will instantly be able to do so if the rod nearest the eye is black, or held so as to throw a deep shade—the line is then much more distinct; but the explanation is not quite the same, but nearly so—it will suggest itself. Two bright pins or needles produce the effect very well in diffused daylight; and the line produced by the shadow of one on the other, and that belonging to the intersection, are easily distinguished and separated.

"If whilst a single bar is moved in one hand several bars or a grate is moved in the other, then spectral lines, equal to the number of bars in the grate, are produced. If one grate is moved before another, then the lines are proportionably numerous; or if the distances are equal, and the velocity the same, so that many spectral lines may coincide in one, that one is so much the more strongly marked. If the bars used be serpentine or curved, the lines may be either straight or curved at pleasure, according as the positions and motions are arranged so as to make the intersecting point travel in a straight, or a curve, or in any other line.

"The cause of the curious appearance produced, when spoke or cog wheels revolve before each other, already described, will now be easily understood; the spokes and cogs of the wheels produce precisely the same effect as the bars held in the hand, and the fixedness of the position of the spectrum depends upon the recurrence of the intersecting or hiding positions, exactly in the same place with equal wheels, provided the opposite motion of each be of equal velocity and the eye be fixed.

"When the wheels were used in the little machine described (Fig. 87), having

equal but oblique teeth, and the obliquity in the same direction, the spectrum was also marked obliquely; but when the obliquity was in opposite directions the spectrum was marked as with straight teeth.

"When equal wheels were revolved with opposite motions, one rather faster than the other, the spectrum travels slowly in the direction of the fastest wheel; when the difference in the velocity of the two wheels was made greater, the spectrum travels faster. These effects are the necessary consequence of the transference of the intersecting points already described, in the direction of the motion of the fastest wheel. When one wheel contains more cogs than the other, as, for instance, twenty-four and twenty-two, then with equal motions the spectrum was clear and distinct, but travelled in the direction of the wheel having the greatest number of teeth.

"When the other wheel was made to move so much faster as to bring an equal number of cogs before the eye, or rather any one part of the eye, in the same time as the other, the spectrum became stationary again. The explanation of these variations will suggest themselves immediately the effects are witnessed. When the motion of the wheels upon the machine is in the same direction, the velocities equal, and the eye placed in the prolongation of the axis of the wheels, no particular effect takes place. If it so happens that the cogs of one coincide with those of the other, the uniform tint belonging to one wheel only is produced. If they project by the side of each other, it is as if the cogs were larger, and the tint is therefore stronger. But, when the velocities vary, the appearances are very curious; the spectrum then becomes altogether alternately light and dark, and the alternations succeed each other more rapidly as the velocities differ more from each other.

"When wheels with radii are put upon the machine, it is easy to observe, in perfection, the optical appearance already referred to, as exhibited by carriage-wheels, &c. (Fig. 85). They should be looked at obliquely, so as to be visually superposed only in part; and, provided the wheels are alike, and both revolving in the same direction with equal velocities, they immediately assume the form described, passing in curves from the axis of one wheel to the axis of the other, much resembling in disposition those curves formed by iron filings between two opposite poles of a magnet.

"If the wheels revolve in opposite directions, then the spectral lines, originating at each axis as a pole, have another disposition, and, instead of running the one set into the other, are disposed generally like the filings about two similar magnetic poles, as if a repulsion existed; not that the curves or the causes are the same, but the appearances are similar. A very little attention will show that all these lines are the necessary consequence of the travelling of successive intersecting points; and any one of them may be followed out by experimenting with the two pasteboard rods already described, these being moved in the hand as if each were the spoke of a wheel.

"All these effects may be simply exhibited by cutting out two equal pasteboard wheels without rims, passing a pin as an axis through each, spinning one upon a mahogany or dark table, and then spinning the other between the fingers over it, so that the two may be visually superposed. If the appearances are observed by a lamp or candle, the wheels should be so held to the light that the shadow of the upper may not fall upon the lower; otherwise the effects are complicated by similar sets of lines which appear upon the lower wheel, and are produced by the shadow of the upper.

"These are the same in form and disposition as in the former, and are even

more distinct; they should be viewed, not through the upper wheel, but directly upon the lower; their explanation has in part been given, and will be sufficiently evident."

Returning to the consideration of Mr. Rose's Photodrome, or "Light-Runner," the construction is simple, and not likely to get out of order.

It consists of two parts. The first part (*b*, Fig. 94) consists of a wheel about four feet in diameter, provided with eight spokes, and wholly constructed of the the best seasoned mahogany. The wheel is driven by a gut band proceeding from a smaller flying-wheel, which is worked by hand. This large wheel is so

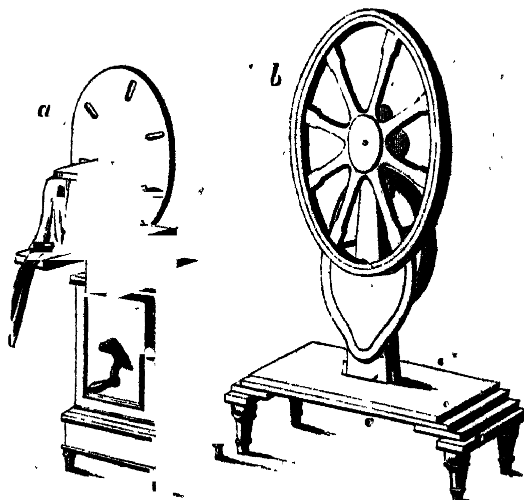


FIG. 94.—*The two portions of Rose's Photodrome, viz., the large and small wheels alluded to.*

arranged on a platform, or other convenient place, that a strong light, arranged in a lantern with a proper lens, casts its rays through one of two apertures in a second disc (*a*, Fig. 94), about two feet in diameter, placed below and in front of it, so that the shadow of the large wheel is distinctly thrown upon the white screen behind. When the large wheel is set in motion, and a certain velocity, from about 250 to 300 revolutions per minute, obtained, all the spokes and the shadows of them disappear, and then the curious effect of the rim or ring of the wheel is shown revolving without any apparent connection with the central axis. Whilst this large wheel is going round, if the spectator looks obliquely through the spokes of the real wheel to those of the shadow-wheel, he will see the curved lines described by Faraday, as obtained by him with his cardboard models in Fig. 86, p. 77. In a favourable position the whole distorted shadow-wheel, with curve lines on a grey ground, becomes visible on a scale not probably contemplated by Faraday with his small cardboard spokes.

These effects being shown with the large wheel, attention is now directed to the second portion of the apparatus, consisting of a disc about two feet in

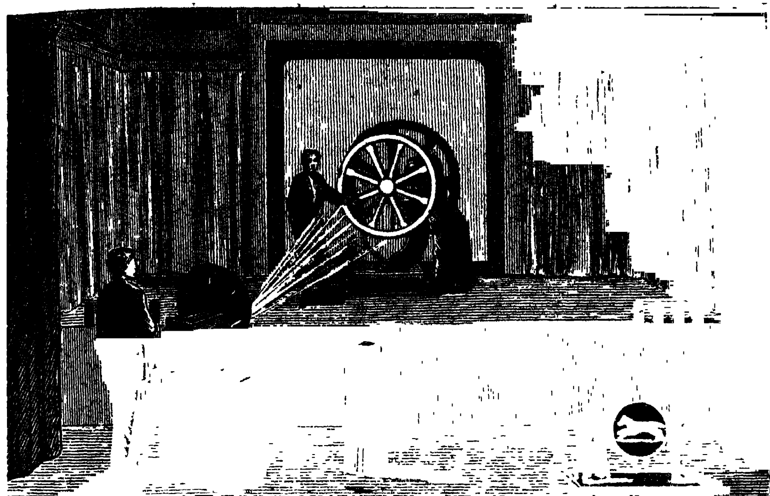


FIG. 95.—*Exhibition of the Photodrome at the Polytechnic.*

diameter, and provided with two apertures. With an ingenious sliding arrangement six or eight apertures can be obtained, if required, but two are preferred for this experiment.

The rays of light, as already described, pass through these apertures every time they come round, and the large wheel being still in motion and the spokes invisible, directly the small disc begins to move and attains a moderate velocity all the spokes and their shadows return. At first they are very hazy and indistinct, and almost semi-transparent; but, as the velocity increases, they become distinctly apparent, and the large wheel appears to be going round slowly and nearly to stand still. The next change in the velocity of the small disc throwing the flashes causes the spokes to be multiplied, generally by five; thus, forty spokes and forty shadows may be counted, the latter being grey, and not black, like the original eight shadows. The next and last increase of velocity in the small disc, which brings it up to about a thousand revolutions in a minute, causes the large wheel—the eight spokes and eight shadows—to appear quite distinct, and at that moment, although the large wheel is going round three hundred times in a minute, *it appears to stand still.*

The flashes of light perform the same duty as the slits or apertures in Plateau's apparatus, and before the large wheel has time to move the light arrives and passes away. If the large wheel was moving at the rate of one thousand revolutions in a minute, no change would occur. It is the difference in the two velocities which determines this curious form of the illusion.

Mr. Rose mentions a most amusing story in connection with the curious illusions produced by the Photodrome, viz., that of the large wheel apparently standing still when it is really moving very fast. It appears that whilst

showing the experiment to a number of working men, at a lecture-hall in Glasgow, one of them rose from his seat, and wanted to creep up quietly to the large wheel, for the purpose of convincing himself by touch that it really was moving. Fortunately, they stopped the man in time, or he would probably have received a blow from the spokes of the wheel which might have broken some finger-bones. This incredulity was an interesting example of the effect of that teaching which grows up with us, viz., that "seeing is believing." Here was a man who had evidently never seen an optical illusion before, and, doubtless, by the time Mr. Rose had finished his beautiful experiments, he discovered that the eye, like the ear, is easily deceived.

LIGHT AND COLOUR.

SPECTRUM ANALYSIS.

ABERRATION AND ACHROMATISM.

In the frontispiece of this book is shown the beautiful apparatus attached to the Duboscq lantern, containing the electric lamp. Such a contrivance, with its lenses and prisms, is a great contrast to the simple means employed by Sir Isaac Newton, nearly two hundred years ago, to effect the same object—viz., the decomposition of light. The great discovery made by Newton, about the year 1672, that light is not of a simple but of a compound nature, was established by the help of a prism (an optical instrument already described at p. 50) through which a sunbeam was permitted to pass. No doubt, whilst moving the prism about in the light the production of colour might have been accidentally discovered, as it would have been by any other careful experimentalist; but it fortunately happened that the discovery fell to the lot of a mind already well prepared to grapple with difficult phenomena, and Newton was soon able to convince himself and others that he had analysed light, and resolved it into seven colours—viz., Red, Orange, Yellow, Green, Blue, Indigo, and Violet. Here was light, not only refracted or bent from its natural course, but spread out—a phenomenon to which the term dispersion is now given. Other lenses or optical instruments possess the same property in a more limited degree, and hence the edges of the pictures or images thrown by convex lenses from the magic lantern show colours. In what are called achromatic lenses, the disagreeable effect upon the eye produced by ordinary lenses is prevented, and the colours neutralized and destroyed. The value of science-teaching as a part of regular education is now fully recognized; but schoolmasters have little time to spare to superintend the manufacture and collection of oxygen in bags, or to put together a voltaic battery, for the purpose of obtaining either the oxy-calcium or the electric light; consequently, the phenomena of light are only taught theoretically instead of experimentally. If a master could teach the leading principles of optics by merely closing the shutters of his room, and allowing a sunbeam of a greater or lesser diameter, determined by different-sized diaphragms, to enter through an aperture into the darkened room, he would be more disposed to impart this kind of knowledge to his boys, because

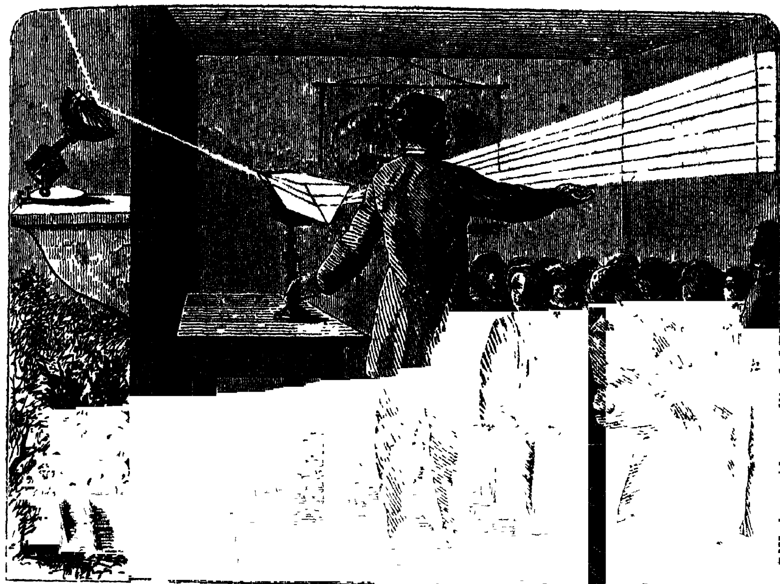


FIG. 96.

The Heliostat, placed on a shelf outside the window, reflecting the ray of light which passes through a hole in a shutter on to a prism, to show the decomposition of light.

the sunbeam would cost nothing, and with the help of an instrument called the Heliostat* (ηλιος, the sun, and στατος, to stand still) the reflected ray of light may always be retained in a fixed direction, notwithstanding the apparent motion of the sun.

In order to obtain a solar spectrum of the most perfect kind, the aperture through which the light passes should be a slit not more than the twentieth part of an inch in breadth, and the length rather less than that of the prism, placed at an angle of sixty degrees, and the spectrum thrown on the white wall or screen, which should be about sixteen or nineteen feet distant. In the frontispiece is represented the lantern containing the electric lamp, connected with a powerful battery, which latter is placed outside the lecture-room. The light is condensed by a plano-convex lens, and passed through a very narrow slit of metal, capable of adjustment by a proper motion, so that it can be made narrower if required. The slice of light, or thin electric light-ray, is now permitted to fall on another double-convex lens, which causes the ray to converge a little more, and to fall upon two hollow prisms filled with bisulphide of carbon, which enjoys a high refractive power. After passing through the two

* These instruments are now sold at a very cheap rate by Messrs Griffin, and can be obtained for £3 or £5.

prisms, it is bent on to the screen in front; and if the battery is in good order, the most vivid colours are obtained.

The seven colours are easily caused to re-unite and form white light, either by passing the dispersed rays through a fish-globe full of water, or by receiving them on to a double-convex lens (A, Fig. 97), or into a concave mirror (B, Fig. 97), or by allowing the spectrum formed by one prism to fall on another, as at C, Fig. 97, of the same nature and at the same refracting angle, but in a reversed position, so that the two outer faces of the two prisms become parallel to each other, and in fact are then equivalent to a piece of flat or plane glass.

A very refined and beautiful experiment, originated in Paris (Fig. 98), is that in which seven mirrors are used, and by arranging them at the proper angles they may be made to reflect each colour separately on to a disc, or the whole may be brought together to produce one spot of white light.

In stating that light is made up of seven colours, it must be borne in mind that they are not considered to represent the ultimate, but proximate analysis of light. One of Brewster's masterly essays is that in which he endeavours to prove that the spectrum is entirely pervaded with the three simple colours, red, yellow, and blue, from which the other colours, orange, green, indigo,

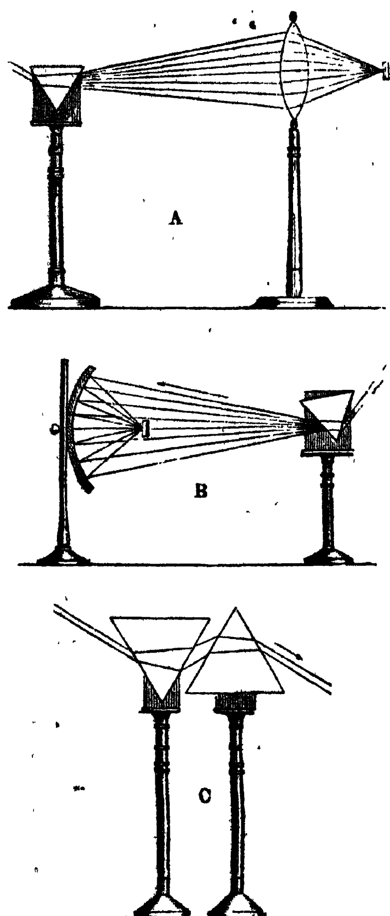


FIG. 97.—*The Recomposition of Light.**

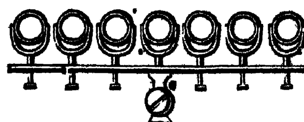


FIG. 98.—*Apparatus with Seven Plane Mirrors for reflecting the seven colours of the Solar Spectrum.*

* Effected in three ways—by a double-convex lens, A; a concave mirror, B; or by a second prism, C.

and violet, arise. By employing the absorptive power of a wedge of blue glass, he was enabled to refute the conclusion deduced by Newton, "That to the same degree of refrangibility ever belongs the same colour, and to the same colour ever belongs the same degree of refrangibility." Sir Isaac examined each colour separately by making a hole in the screen upon which the spectrum fell exactly in the centre of each colour, and allowing that colour to fall upon another prism; and finding that this second refracting surface did not change or decompose the special colour under examination into any other colours, he concluded "That the light of each different colour had the same index of refraction;" and he called such light homogeneous or simple light, whilst ordinary or white light he termed heterogeneous or compound. It is this enunciation of Newton which Brewster disproved by the following experiments:—He says, "If we take a piece of blue glass, like that generally used for finger-glasses, and transmit through it a beam of white light, the light will be a fine deep blue. This blue is not a simple homogeneous colour like the blue or indigo of the spectrum, but is a mixture of all the colours of white light which the glass has not absorbed, and the colours which the glass has absorbed are those which the blue wants of white light, or which, when mixed with this blue, would form white light. In order to determine what these colours are, let us transmit through the blue glass the prismatic spectrum; or, what is the same thing, let the observer place his eye behind the prism, and look through it at the sun, or rather at a circular aperture made in the window-shutter of a dark room. He will then see through the prism the spectrum as far before the aperture as it would be above the spot when shown on the screen. Let the blue glass be now interposed between the eye and the prism, and a remarkable spectrum will be seen, deficient in a certain number of its differently coloured rays. A particular thickness absorbs the middle of the red space, the whole of the orange, a great part of the green, a considerable part of the blue, a little of the indigo, and very little of the violet. The yellow space, which has not been much absorbed, has *increased in breadth*. It occupies part of the space formerly covered by the orange on one side, and part of the space formerly covered by the green on the other. Hence it follows that the blue glass has absorbed the red light which, when mixed with the yellow light, constituted orange, and has absorbed also the blue light which, when mixed with the yellow, constituted the part of the green space next the yellow. We have therefore, by absorption, decomposed green light into yellow and blue, and orange light into yellow and red; and it consequently follows that the orange and green rays of the spectrum, though they cannot be decomposed by prismatic refraction, can be decomposed by absorption, and actually consist of two different colours possessing the same degree of refrangibility. *Difference of colour is, therefore, not a test of difference of refrangibility*. Red, yellow, and blue light exist at every point of the solar spectrum. The existence of these primary colours in the spectrum, and the mode in which they produce, by their combination, the seven secondary or compound colours which are developed by the prism, will be understood from Fig. 99, where M N is the prismatic spectrum, consisting of three primary spectra of the same lengths,

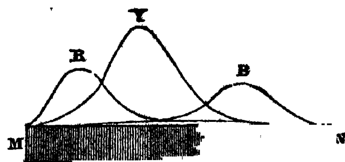


FIG. 99.

M N, viz., a red, a yellow, and a blue spectrum. The red spectrum has its maximum intensity at R; and this intensity may be represented by the distance of the point R from M N. The intensity declines rapidly to M and slowly to N, at both of which points it vanishes. The yellow spectrum has its maximum intensity at Y, the intensity declining to zero at M and N; and the blue has its maximum intensity at B, declining to nothing at M N. The general curve which represents the total illumination at any point will be outside these three curves, and its ordinate at any point will be equal to the sum of the three ordinates at the same point. Thus the ordinate of the general curve at the point Y will be equal to the ordinate of the yellow curve, which we may suppose to be 10, added to that of the red curve, which may be 2, and that of the blue, which

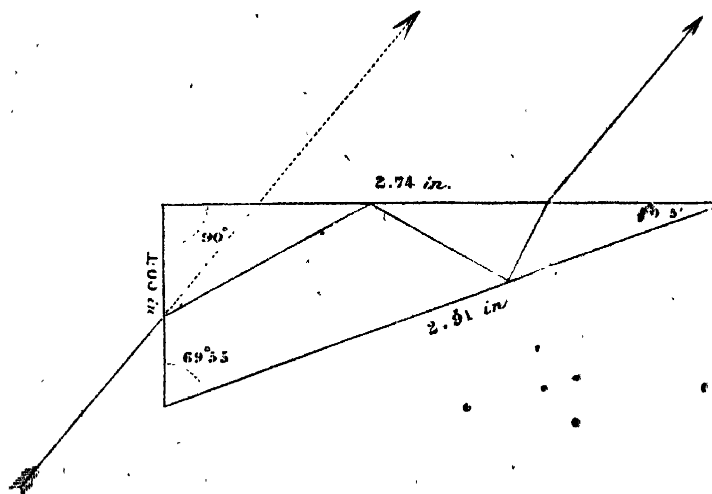


FIG. 100.—*Herschel's Direct-Vision Prism.*

may be 1. Hence the general ordinate will be 13. Now, if we suppose that 3 parts of yellow, 2 of red, and 1 of blue make white, we shall have the colour at Y equal to 3+2+1, equal to 6 parts of white mixed with 7 parts of yellow; that is, the compound tint at Y will be a bright yellow, without any trace of red or blue. As these colours all occupy the same place in the spectrum, they cannot be separated by the prism; and if we could find a coloured glass which would absorb 7 parts of the yellow, we should obtain at the point Y a white light which the prism could not decompose."*

It may be useful to mention that, with Herschel's direct-vision prism, filled with bisulphide of carbon, the trouble required in adjusting the lantern so as to throw the spectrum on to the disc is obviated, and the lantern, with its prism attached, may be placed directly in front of the screen, as in any other ordinary optical experiment.

* Helmholtz and Airy have thrown great doubts on Brewster's experiments and theory of the spectrum.

PHYSICAL PROPERTIES OF THE SPECTRUM.

It has been shown how a ray of light can be separated into its proximate or ultimate colours. These various portions of coloured light have certain distinct properties, which have been most carefully investigated by different physicists. The illuminating power of the spectrum, as might be imagined, exists in the most luminous portion of the band of colours, viz., in the yellow light; and experiments carefully conducted by Herschel and Frauenhofer confirm this fact, and show that the greatest amount of light exists nearer the red than the violet end of the spectrum. The calorific power of the spectrum increases gradually from the blue colour; it rises to its maximum in the red; but, what is most curious, it reaches its greatest elevation beyond the limits of the visible red ray, or red end of the spectrum. The invisible rays of heat are, therefore, more powerful than the other heat-giving rays of the spectrum accompanied with light, as in the yellow, orange, or red colours; the luminous radiations do not give so much heat as the non-luminous ones; and Tyndall, speaking of this remarkable circumstance, says, "In the region of dark rays beyond the red the curve shoots up in a steep and massive peak, a kind of Matterhorn of heat, which dwarfs by its magnitude the portion of the diagram representing the luminous radiation."

The chemical influence of the spectrum, unlike the heating and illuminating rays, is at its minimum at the red end, and rises gradually in intensity towards the violet. Light acts as a chemical agent not only with certain portions of its luminous rays, but, like heat, with its non-luminous rays. Ritter, of Jena, discovered that chloride of silver was acted upon and blackened beyond the violet end of the spectrum. Dr. Herschel and Dr. Wollaston confirmed this fact. These chemical or actinic rays have been carefully studied and most industriously employed, so that a new art has been created, called Photography, which, in a thousand different ways, is now made subservient to the requirements of man. Moser has discovered that certain rays have the power to set up chemical change, and this once begun may be continued with other coloured rays, that could not in themselves produce chemical decomposition. An iodized silver plate, with an engraving placed over it, was exposed to light until the action had commenced; if this plate was then placed under a violet glass, the picture was soon obtained; whilst a long time elapsed, and the result was imperfect, when the same plate, after exposure to sunlight, was placed under a red glass. If, however, the prepared plate was first exposed in a camera to a blue light, and then placed under a red glass, the picture was speedily obtained. In the early portion of this article phosphorescence has been considered, and here it may be mentioned that Becquerel calls the rays capable of setting up or commencing chemical action "exciting rays," and others which only possess the power of continuing a chemical change "phosphoregenic" or "continuing rays," and has identified the latter with the power possessed by light of rendering certain bodies luminous. (See p. 9.) It is the phosphoregenic rays, extending from the indigo to beyond the violet ray, which render certain bodies phosphorescent by insolation. Becquerel has invented a most ingenious instrument, called the Phosphoroscope, by which substances can be viewed directly after exposure to light, and the time of the duration of the phosphorescent power accurately determined. Thus several bodies, which are only phosphorescent for some fraction of a second, have been added to the long list of substances affected in a similar but more decided manner.

When the bright rays from the electric lamp are passed through blue glass, and then permitted to fall upon a plate of glass coloured yellow by the oxide of uranium, the latter becomes self-luminous, and emits rays which are altered in their vibratory power; the original rays have undergone a change in their refrangibility.

To these phenomena, which Professor Stokes has investigated with the greatest care, the title of fluorescence, or internal dispersion, has been given. Figures or letters painted with a strong solution of sulphate of quinine in tartaric acid become curiously self-luminous when the rays passed through blue or, better still, violet glass are allowed to fall upon them. A little sulphur burnt in a jar of oxygen emits rays which render paper painted with an alcoholic solution of stramonium self-luminous.

A tube of uranium glass, conveying the coil-discharge *in vacuo*, is similarly affected by this peculiar electric light. It was ascertained that prisms made of glass appeared to absorb a larger number of the more refrangible rays, and Professor Stokes found that by using prisms made of quartz he could obtain, with the electric light, a spectrum six or eight times as long as the ordinary one; and his experiments indicate that the chemical, the luminous, the phosphorogenic rays, or rays of high refrangibility, are intimately connected with each other, and are only so many effects of one and the same cause.

THE DARK OR FIXED LINES IN THE SOLAR SPECTRUM.

At the beginning of the present century, in the year 1802, Dr. Wollaston announced that he had discovered two dark lines, one in the green and the other in the blue space of the solar spectrum, formed by a prism of flint glass. This very humble beginning, at first exciting little or no attention, has led on to a series of most valuable experiments, which have not only been made with terrestrial substances, but have even by analogy conducted the aspiring philosopher to the far-distant celestial bodies, where, by the help of the light emitted and reflected from them, certain conclusions as to their physical nature and aspect have been arrived at. Wollaston also showed his great sagacity as an observer, in discovering the *bright lines* in the spectrum of the electric spark.

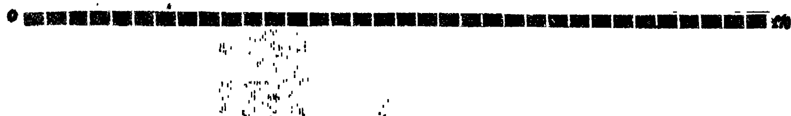


FIG. 101.—*Frauenhofer's Seven Lines in the Solar Spectrum.*

About the year 1814, the celebrated mathematical optician, Frauenhofer, of Munich, repeated Wollaston's experiment, and not only found the two lines, but discovered that the spectrum was crossed throughout its entire length by a great number of dark lines of different breadths. In consequence of the industry with which Frauenhofer continued the investigation, and the care with which he mapped out and measured the exact place of each most important line in the spectrum, they have by universal consent been called Frauenhofer's

lines; of these seven have been particularly distinguished, and are marked B, C, D, E, F, G, and H, Fig. 101.

Thus B is in the red space, near the end; C is near the edge of the red; D is in the orange, and is a strong double line, separated by a bright one; E is in the green, consisting of several, the middle one being the strongest; F is in the blue; G is in the indigo; and H in the violet. These special lines, so carefully determined by Frauenhofer, have remained as fixed points of reference. But they do not give the student any idea of the immense number of lines which are to be found throughout the whole length of the visible portion of the solar spectrum, and even in the invisible rays rendered visible by the experiments of Professor Stokes. Their name is legion, and they are to be counted by hundreds and thousands; and so far back as the year 1814 Frauenhofer had counted 600. In the year 1830 Simms constructed the first most important spectrum apparatus. In 1832 Brewster carefully examined the dark lines produced by passing the spectrum obtained from an artificial source of light through nitrous acid gas; at first he thought they were identical with the dark lines in the solar spectrum, but Professors Daniell and Miller proved that this was not the case, and that they were produced by the absorptive power of the gas. In the year 1835 Wheatstone observed that the incandescent vapour of metals, obtained by the electric discharge through metallic poles, gave certain coloured lines peculiar to each metal. He concluded that the electric spark results from the volatilization and ignition, not the combustion, of the ponderable matter of the poles itself, as the same phenomena were observed in hydrogen; and he states that these differences of spectra obtained from various metallic poles "are so obvious, that one metal may instantly be distinguished from another by the appearance of its spark; and we have here a mode of discriminating metallic bodies, more readily applicable even than a chemical examination, *which may hereafter be employed for useful purposes.*" How true this prediction proved is shown in the construction and use of the apparatus now employed to obtain the spectra of terrestrial metals for the purpose of comparing their coloured lines with the black lines obtained from the light of the sun, the fixed stars, &c. The apparatus made by Huggins and Miller, and applied to the heavenly bodies, includes a slit for the admission of light, and over one half of it is placed a right-angled prism to receive the light from the electric sparks obtained from metallic poles and sent by a mirror through an aperture to the prism. The lines obtained from any given metal, such as sodium, could be at once compared by exact measurement with similar black lines obtainable from solar light, and the two identified with each other. It remained for Bunsen and Kirchoff, in 1859, to sum up all the labours of the clever men who had preceded them, and, with the help of their own experiments, to read Frauenhofer's black lines as if they were hieroglyphics, the key to which they had at last discovered by elaborate experiments. Since Kirchoff's discoveries, Mr. Huggins and Dr. Miller have steadily persevered in the same path of spectrum analysis, and have given the world some remarkable facts, showing the nature of the planets, fixed stars, nebulæ, and comets.

The chief credit has fallen to Bunsen and Kirchoff, because they skilfully grasped the whole phenomena, and reduced them to a perfect system; it should, however, be remarked that, as far back as the year 1752, Thomas Melville investigated the nature of coloured flames, and specially observed the yellow flame, which no doubt gave Brewster the idea of the monochro-

matic lamp and light, obtained with alcohol and salt. In 1822 Sir John Herschel remarks that, "The colours thus communicated by different bases to flame affords in many cases a ready and neat way of detecting extremely minute quantities of them." In 1834 Mr. Fox Talbot, speaking of his experiments with the red tint of flame produced by lithium and strontium, says, "I hesitate not to say that optical analysis can distinguish the minutest portion of these substances from any other, with as much certainty as, if not more than, by any other method." It will thus be seen that English philosophers were not wholly ignorant of the primary truths which led to the grand generalizations of Kirchoff. Since the first instrument used by Bunsen and Kirchoff, other and more perfect instruments have been made for spectrum analysis. Probably one of the most simple in construction is that made by Mr. John Browning, of 111 Minories, with the assistance of Mr. Herschel, and called by him the Herschel-Browning direct-vision spectroscope, in which the direct vision is produced by a combination of two direct-vision prisms.

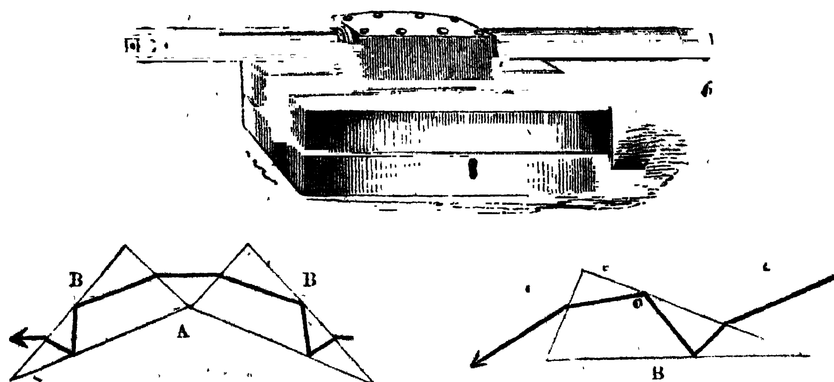


FIG. 102.—*The Herschel-Browning Direct-Vision Spectroscope.*

A, arrangement of the two prisms, B B being direct-vision prisms.

For quick examination of atmospheric lines, and for noting the changes that occur near the horizon, or in any particular direction, this form of the spectroscope is one of the best yet devised, as it can be instantaneously and accurately pointed at any cloud in any direction. Its dispersion and precision are so great as to divide Frauenhofer's line D with a magnifying power of only 5.

Another form of spectroscope, which is exceedingly useful to the student, has a prism of extremely dense glass of superior workmanship. (Fig. 103.) The circle is divided, and reads with a vernier, thus dispensing with the inconvenience of an illuminated scale. This arrangement possesses the very great advantage of giving angular measures in place of a perfectly arbitrary scale. The slit is also furnished with a reflecting prism, by means of which two spectra can be shown in the field of view at once.

For elaborate researches a larger spectroscope (Fig. 104), containing four dense glass prisms, and a telescope with object-glasses of 1¼ in. diameter and

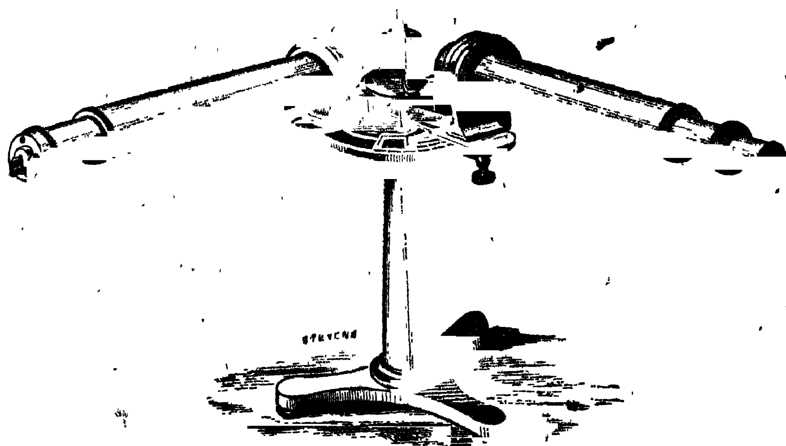


FIG. 103.

18 in. focal length, may be employed. A powerful train of eleven prisms was arranged by Mr. Gassiot; the prisms were hollow, and filled with bisulphide of carbon. It is described in the "Phil. Mag." [4] xxviii. 69.

Mr. Browning has had great experience in the construction of spectroscopes; he made the Kew Observatory spectroscope, furnished with nine glass prisms, another of eleven fluid prisms, which he made for T. P. Gassiot, Esq., and also the spectrum apparatus constructed for William Huggins, Esq., for his important researches on the spectra of the fixed stars; and therefore his directions for the use of the spectroscope are given here.

HOW TO USE THE SPECTROSCOPE.

"Screw the telescope carrying the knife-edges at the small end into the upright ring fixed on to the divided circle, and the other telescope into the ring attached to the movable index. Now place any common bright light exactly in front of the knife-edges, and while looking through the telescope on the movable index (having first unscrewed the clamping screw under the circle), turn the telescope with the index round the circle until a bright and continuous spectrum is visible.

TO OBTAIN THE BRIGHT LINES IN THE SPECTRUM GIVEN BY ANY SUBSTANCE.

"Remove the bright flame from the front of the knife-edges, and substitute in its place the flame of a common spirit-lamp, or, still better, a gas jet known as a Bunsen's burner (Fig. 105). Take a piece of platinum wire, about the substance of a fine sewing needle, bend the end into a small loop about the eighth of an inch in diameter; fuse a small bead of the substance or salt to be experimented on, into the loop of the platinum wire, and, attaching it to any sort of light stand or support, bring the bead into the front edge of the

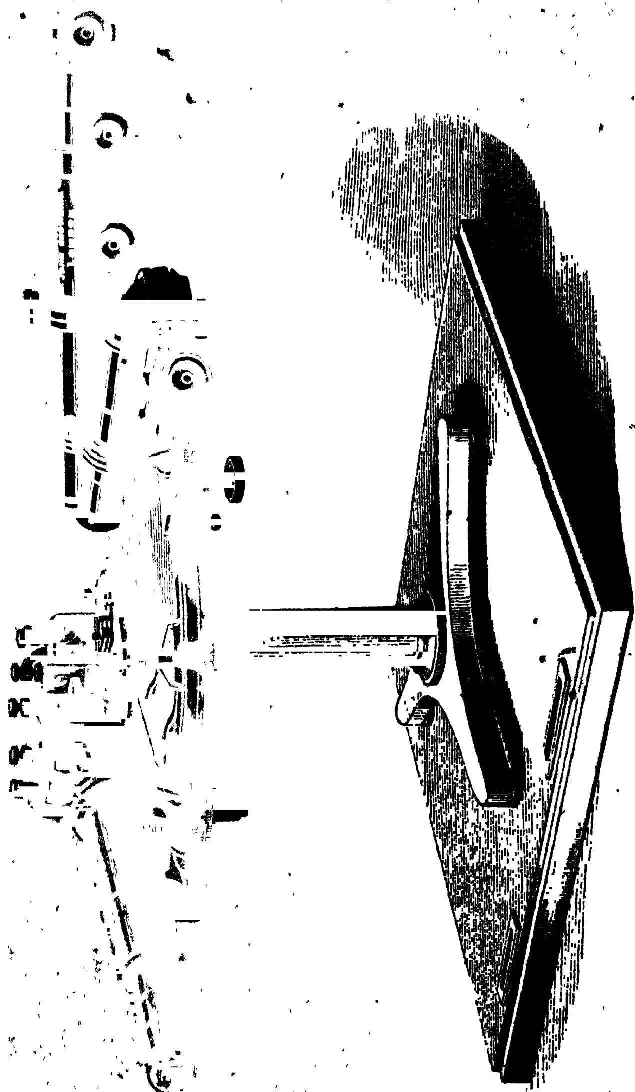


FIG. 104.—*The Gassiot Spectroscope.*

flame, a little below the level of the knife-edges. If the flame be opposite the knife-edges on looking through the eye-piece of the telescope, the fixed lines due to the substance will be plainly visible. When minute quantities have to be examined, the substance should be dissolved, and a drop of the solution, instead of a soild bead, be used on the platinum wire.

"The delicacy of this method of analysis is very great. Swan found, in 1857 (Ed. Phil. Trans., vol. xxi., p. 411), that the lines of sodium are visible when a quantity of solution is employed which does not contain more than 1-2,500,000th of a grain of sodium.

"To view Frauenhofer's lines on the solar spectrum, it is only necessary to turn the knife-edges towards a white cloud, and make the slit formed by the knife-edges very narrow, by turning the screw at the side of them. In every instance the focus of the telescope must be adjusted in the ordinary way, by sliding the draw-tube until it suits the observer's sight, and distinct vision is obtained.

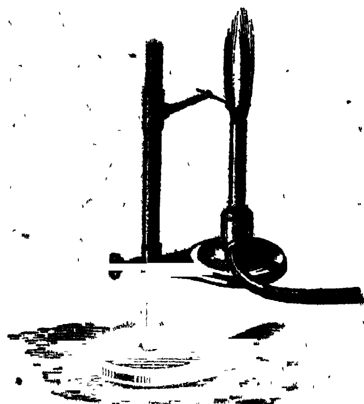


FIG. 105.—*A Bunsen Burner, with Ring-stand, supporting the Platinum Wire*

"It should be noted that lines at various parts of the spectrum require a different adjustment in focusing the telescope.

"The small prism turning on a joint in front of the knife-edges is for the purpose of showing two spectra in the field of view at the same time. To do this it must be brought close to the front of the knife-edges. Then one flame must be placed in the position in which the flame of the candle is shown in the small figure, and the other directly in front of the slit. On looking through the telescope as before described, the spectra due to the two substances will be seen one above the other.

"When the slit is turned towards a bright cloud, and a light is used in the position of the candle flame, the spectrum of any substance may be seen, compared with the solar spectrum. In this manner Kirchoff determined in the solar spectrum the presence of the lines of the greater number of the elements which are believed to exist in the sun.

PROFESSOR STOKES'S ABSORPTION BANDS.

"The instrument is expressly adapted to the prismatic analysis of organic bodies, according to the method recommended by Professor Stokes, in his lecture at the Chemical Society, printed in the 'Chemical News.'

"To observe these bands it is only necessary to place a very dilute solu-

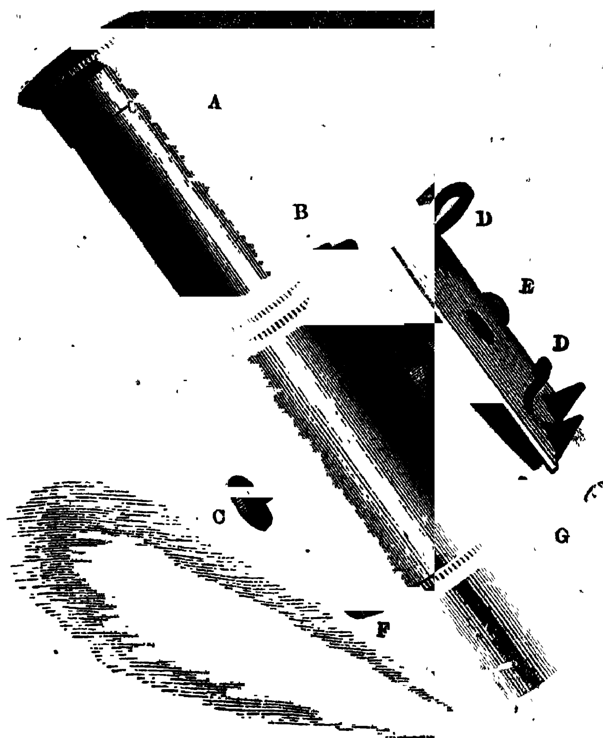


FIG. 106.

tion of the substance in a test-tube, then fix the test-tube in the small clip attached to a ring, which slips on in front of the knife-edges. Upon bringing any bright light in front of the tube, on looking through the telescope, if the instrument has been properly adjusted, a bright spectrum will be seen, interrupted by the dark bands due to the substance in solution.

"One of the simplest and most interesting experiments of this kind can be made by preparing dilute solutions of madder, port wine, and blood.

"In these very dilute solutions no difference can be detected by the unassisted eye; but on submitting them, in the manner already described, to the test of spectrum analysis, very different appearances will be presented.

"The absorption bands may, however, be most conveniently examined, and accurately investigated, by means of Sorby and Browning's new Micro-spectroscope."

As will be seen from Fig. 106, it is a very compact piece of apparatus, very ingenious in construction, and consisting of several parts. The prism is contained in a small tube, which can be removed at pleasure. Below the prism is an achromatic eye-piece, having an adjustible slit between the two lenses; the upper lens being furnished with a screw motion to focus the slit. A side

slit, capable of adjustment, admits, when required, a second beam of light from any object whose spectrum it is desired to compare with that of the object placed on the stage of the microscope. This second beam of light strikes against a very small prism suitably placed inside the apparatus, and is reflected up through the compound prism, forming a spectrum in the same field with that obtained from the object on the stage

A is a brass tube carrying the compound direct-vision prism.

B is a milled head, with screw motion to adjust the focus of the achromatic eye-lens.

C, milled head, with screw motion to open or shut the slit *vertically*. Another screw at right angles to C, and which, from its position, could not be shown in the cut, regulates the slit horizontally. This screw has a larger head, and when once recognized cannot be mistaken for the other.

D D, an apparatus for holding small tube, that the spectrum given by its contents may be compared with that from any other object on the stage.

E, square-headed screw, opening and shutting a slit to admit the quantity of light required to form the second spectrum. Light, entering the round hole near E, strikes against the right-angled prism which we have mentioned as being placed inside the apparatus, and is reflected up through the slit belonging to the compound prism. If any incandescent object is placed in a suitable position with reference to the round hole, its spectrum will be obtained, and will be seen on looking through it.

F shows the position of the field lens of the eye-piece.

G is a tube made to fit the microscope to which the instrument is applied. To use this instrument, insert G, like an eye-piece is in the microscope-tube, taking care that the slit at the top of the eye-piece is in the same direction as the slit below the prism. Screw on to the microscope the object-glass required, and place the object whose spectrum is to be viewed on the stage. Illuminate with stage mirror if transparent, with mirror and Lieberkuhn and dark well if opaque, or by side reflector, bull's-eye, &c. Remove A, and open the slit by means of the milled head, not shown in cut, but which is at right angles to D D. When the slit is sufficiently open, the rest of the apparatus acts like an ordinary eye-piece, and any object can be focused in the usual way. Having focused the object, replace A, and gradually close the slit till a good spectrum is obtained. The spectrum will be much improved by throwing the object a little out of focus.

Every part of the spectrum differs a little from adjacent parts in refrangibility, and delicate bands or lines can only be brought out by accurately focusing their own parts of the spectrum. This can be done by the milled head B. Disappointment will occur in any attempt at delicate investigation, if this direction is not *carefully attended to.*

When the spectra of very small objects are to be viewed, powers of from ½ in. to 1-20th, or higher, may be employed.

Blood, matter, aniline red, permanganate-of-potash solution (quite fresh), are convenient substances to begin experiments with. Solutions that are too strong are apt to give dark clouds instead of delicate absorption bands.

Mr. Browning makes small cells and other contrivances to hold fluids for examination.

The spectra obtainable from solid, liquid, and gaseous incandescent bodies may be arranged in three orders.

A spectrum of the first order is that which is produced by a solid incan-

descent substance, such as charcoal. The band of colours is continuous from red to violet, and therefore can teach little or nothing of the constitution of the body producing the light; such a spectrum could not be employed for analytical purposes. A spectrum of the second order differs essentially from the first, inasmuch as the colours are not continuous, but consist of distinct coloured bands; it can only be obtained from light emitted from incandescent gases; and any substance which can be converted into a gaseous state by intense heat without undergoing decomposition will afford distinct bands of colour, which are always the same. The metal silver placed in a cup-shaped charcoal pole and connected with the other pole, in the electric lantern figured in the frontispiece, is converted into silver gas, and produces on the disc two distinct green lines. (See Frontispiece.)

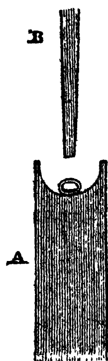


FIG. 107.
Arrangement of Charcoal Crucible A, containing silver. Contact is made with the charcoal pole B, and the metal vapourized.

Thallium—so cleverly discovered by Mr. Crookes, in 1861, in certain kinds of iron pyrites, and so called from the Greek because it produces a splendid green flame—would probably have been unknown but for this new method of analysis. The attention of Mr. Crookes was first directed to the splendid green line as obtained from certain specimens of pyrites, and it was by following up this simple fact—this slender clue—that he was at last enabled to isolate the body that produces the green lines, and confidently pronounce it to be a metal. The spectrum of thallium is shown in the frontispiece. In projecting metal spectra on to the disc, it must be understood that for exact purposes of research they cannot be so truthful as the spectra results obtained by the instruments described on p. 95. The optical arrangements required to show the spectra of incandescent metals to a large audience on the disc cannot be compared to the elaborate instruments already mentioned. Moreover, the charcoal crucible and points contain ash consisting of alkaline earths and salts, which must interfere with the spectrum, results. A spectrum of the third order is obtained when the regularity of the spectrum is interfered with by black fixed lines. Such a spectrum is always obtained from the rays of the sun. As Mr. Huggins remarks, "These dark spaces are not produced by the source of light." They tell us of vapours through which the light has passed on its way, and which have robbed the light by absorption of certain definite colours or rates of vibration. A very simple mode of showing such a spectrum crossed by dark lines is to interpose between the slit of the electric lantern and the double-convex lens a vessel containing some nitrous acid gas. Directly this is done, all the visible indigo, blue, and green colours vanish, and the remainder of the spectrum is crossed with numerous dark lines. In using the electric lantern it must always be borne in mind that if the aperture or slit is too widely opened the dark lines are very indistinct. The slit should be very narrow indeed to display the dark lines sharp and distinct. A more instructive mode is first to produce the two yellow lines representing the spectrum of sodium, and then with a peculiar-shaped crucible (Fig. 108).

It was by this and kindred experiments that Kirchoff showed that if vapours of terrestrial substances come between the eye and an incandescent body,

they cause groups of dark lines, and, further, that the group of dark lines produced by each vapour is identical in the number of lines and in their position in the spectrum with the group of lines of which the light of the vapour consists when it is luminous.

The reversal of the spectrum of coloured flame, and the mode in which he obtained the proof of the identity between the terrestrial sodium line and the dark lines similarily placed in the solar spectrum, is thus described by Kirchoff:

"In order to test by direct experiment the truth of the frequently asserted fact of the coincidence of the sodium lines with the lines D (Frauenhofer), I obtained a tolerably bright solar spectrum, and brought a flame coloured by sodium vapour in front of the slit. I then saw the dark lines D change into bright ones. The flame of a Bunsen's lamp threw the bright sodium lines upon the solar spectrum. In order to find out the extent to which the intensity of the solar spectrum could be increased without impairing the distinctness of the sodium lines, I allowed the full sunlight to shine through the sodium flame upon the slit, and, to my astonishment, I saw that the dark lines D appeared with an extraordinary degree of clearness."

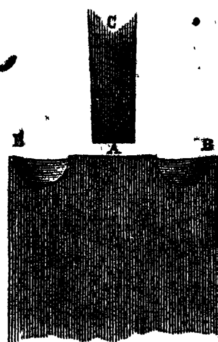


FIG. 108.

The section of the Crucible to be used for showing the reversal of the bright sodium lines, of which A is the central hole, and contains some chloride of sodium, and B B a ring or trench all round A, in which metallic sodium is placed; C, the upper charcoal pole.

With respect to this important experiment, showing the reversal of the sodium lines, perhaps the most simple experiment is that of Roscoe, who seals up some of the metal sodium in a vacuum tube; and on volatilizing the metal the vapour is colourless by white light, but dark and opaque when the monochromatic or yellow light of sodium is shown behind it.

It was by the exact reversal of the bright terrestrial lines, and the absolute identity in position of the bright terrestrial and dark solar lines, that Kirchoff discovered the elements that exist in the sun, viz., hydrogen, sodium, magnesium, iron, calcium, nickel, chromium, copper, zinc, barium, and probably strontium, cobalt, cadmium.

At p. 92, and in Fig. 101, are shown the lines B, C, D, E, F, G, and H, which are called Frauenhofer's principal fixed dark lines in the solar spectrum. The labours of Kirchoff have now almost interpreted the whole of these lines, which are read as follows:

C, F, and G are Hydrogen.
D is Sodium.
E is Iron.
H, Aluminium.
C, Magnesium.

The limits of this work do not permit the consideration of stellar chemistry, and the extremely valuable researches of Mr. Huggins and Dr. Miller in this direction; but the reader is referred to Mr. Huggins's discourse "On the Results of Spectrum Analysis applied to the Heavenly Bodies," published by Ladd; or to Mr. Watt's "Dictionary of Chemistry," for a complete *résumé* of this subject. This much may be said, that spectrum analysis proves that the fixed stars are suns like our own—a fact which could only be assumed and taken for granted before the important experiments of Kirchoff, Huggins, and Miller.

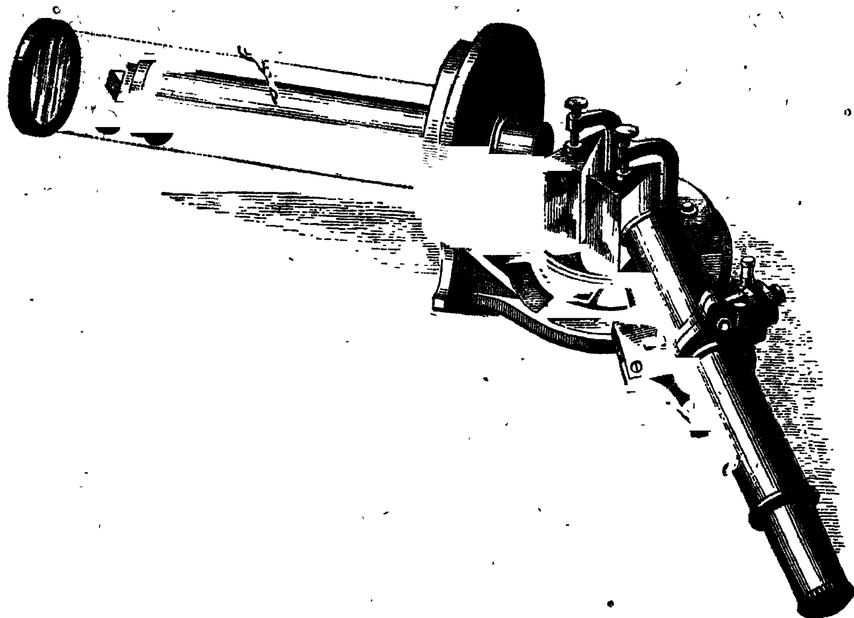


FIG. 109.—*Star Spectroscope, with adjustible Reflecting Prism and Mirror.*

With finest object-glass micrometric apparatus for measuring the lines of the spectrum to 1-10,000th of an inch, extra eye-piece, and ivory tube to reader of vernier, as made for W. Huggins, Esq., F.R.S., and used during the observation of the red flames of the sun in India, August, 1868.

Moreover, the spectroscope has discovered the real nature of the "red flames" or "prominences" of the sun, which are invisible under ordinary circumstances, being overpowered by the dazzling brilliancy of the rays which proceed from the sun; but visible during the few minutes that elapse during a total eclipse of the sun, as in the one which created so much interest in August of the present year, 1868, visible only in the line or path of the shadow, which fell in India. Four xpeditions went to India to observe the red flames; they were all armed with the spectroscopic apparatus, and their united statements all agree that the red flames belong to the sun, and that, as they give bright lines which belong only to spectra of the second order, they must be enormous *gas-heaps*, intensely ignited or self-luminous. The bright lines chiefly observed appear to be those which belong to hydrogen gas and sodium, at least so far as we know at present (September, 1868); and this interesting statement was made through the telegrams from Major Tennant, Lieutenant Herschel, and M. Jannsen, which arrived in England, and were all sent independently of each other. As the red flames belong to the sun and show bright lines in the spectroscope, are they great volumes of the photosphere thrust out (like the pips and juice of a squeezed gooseberry) beyond the last or gaseous atmosphere, which usually robs the light from the photosphere of its beautiful coloured bands,

and changes them to dark lines? for where light is not, there can only be darkness.

These and other facts are discoverable by another modification of the spectroscopic arrangement (Fig. 109), as constructed by Mr. Browning.

SPHERICAL ABERRATION.

In using an ordinary concave mirror the experimentalist cannot fail to notice that the rays reflected from the part near the circumference do not come to the same meeting-point or focus as the rays reflected from parts near the centre. (Fig. 110.) It is evident that the rays A B, A C, come to a focus at G, which is further off than the focus F from the parallel rays D D, D D. The distance between F and G, the two foci, is called the longitudinal spherical

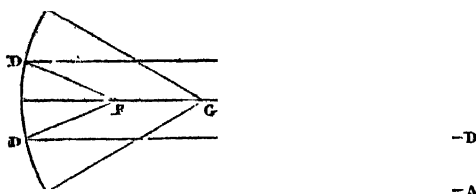


FIG. 110.—*Concave Mirror, showing the Aberration of the Rays of Light.*

aberration. The natural consequence must be that an image projected by an ordinary concave mirror will be confused, because the eye has to look at a double image, the one superposed on the other. To get rid of the rays from the outer part of the mirror it is usual to employ a screen, so that the rays D D, D D, from the central part of the mirror only are used.

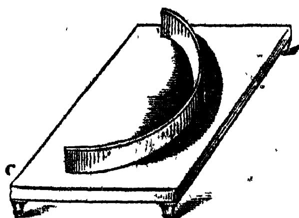


FIG. 111.—*Production of Caustic Curves.*

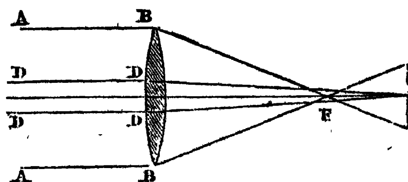


FIG. 112.

Arising from this circumstance is the unequal illumination of a white ground on which rays are reflected to different foci, and the production of symmetrical curves, termed caustic lines or caustic curves, in the study of which mathematicians have been most industrious. Brewster lays claim to the following method of exhibiting caustic curves. He recommends the use

of a piece of steel spring highly polished, or, better still, polished silver, which is to be bent into a concave figure and placed vertically on its edge upon a piece of card or white paper, and when exposed either to the rays of the sun or any good artificial light, the curves shown in Fig. 111 are well defined.

In the same way, passing from reflecting to refracting bodies, the spherical figure of a convex lens causes the rays which fall near the outer edge to come to a focus nearer the lens than the rays which are refracted from the centre.

The result, as might be expected, is just the reverse of the concave mirror. The rays A B, A B, Fig. 112, falling on the margin of the double-convex lens are refracted to a focus at F, whilst those rays, D D, D D, which fall near the axis of the lens come together at a more remote point, viz., at C. Here again a screen or diaphragm cutting off the rays refracted from the outer edge of the lens gives a better image; the picture produced by such a lens, provided with a screen, can be focused more distinctly; hence telescopes, microscopes, cameras, oxy-hydrogen lanterns, &c., &c., are usually fitted with diaphragms, which reduce the light, but cause the images to become more distinct. The lens of the eye would, from this cause, project on to the retina a confused or double picture, which might render vision extremely imperfect; this, however, is prevented by the iris, which acts as a diaphragm, thus the aberration of sphericity is corrected.

THE DISPERSION OF LIGHT, OR CHROMATIC ABERRATION.

If light consisted of a series of coloured rays, every one of which possessed the same index of refraction when they fall upon a glass lens, they would all come together in the same spot, and white light only would be obtained; but this is not the case, and it is known in practice that lenses, and especially condensing lenses, project coloured rings, and give images with coloured edges. And this is not remarkable when it is remembered that a double-convex lens may be regarded as a series of prisms united at their bases, and therefore capable of decomposing or dispersing light. It is a singular fact that Sir Isaac Newton considered, from the experiments he had tried with various prisms, that dispersion was proportioned to refraction, and he believed that all substances had the same chromatic aberrations when formed into lenses, and that any combination of a concave with a convex glass would produce colour with refraction. Newton reasoned only from the facts he had acquired on the dispersive powers of bodies, and pronounced the construction of achromatic telescopes which should not project images with coloured edges to be impossible. The fallibility even of his great mind is shown by the fact that, a few years after his death, Hall in 1733, and Dolland, the famous optician, in 1757, demonstrated that by using two media, viz., crown and flint glass, of different refractive and dispersive powers, a lens may be formed which is achromatic.

The principle of the achromatic lens is not complicated or difficult to understand, provided the previous matter relating to compound and simple colours (p. 89) has been already studied. Given a lens made of a certain glass, and projecting, amongst other colours, a ring of red light, what colour, projected from another lens, is required to neutralize it? The answer is obvious: any colour which together with the red light would form white light. That colour must be green, because it contains yellow and blue; and, as already shown, red, yellow, and blue form white light. In the adjustment of the two lenses

forming the achromatic (Fig. 113), it is so arranged that the colours which would be separately produced by each lens shall, when combined, by their unequal dispersion fall together at the same spot and unite together. Any two colours which unite and form white light are said to be complementary, and there is a very conclusive experiment which may be performed with polarized light passed through a selenite slide placed behind a Nicol's prism composed of

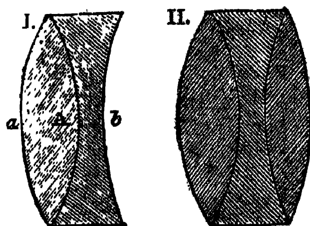


FIG. 113.

No. I, Dolland's Achromatic Lens, consisting of one double-convex crown glass lens, *a*, and another concavo-convex lens of flint glass, *b*; No. II., Dr. Blair's Achromatic Lens, composed of two double-convex lenses of crown glass, enclosing a solution of chloride of antimony.

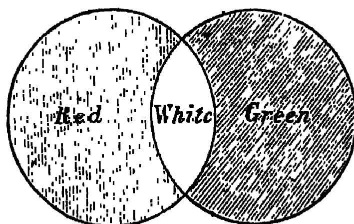


FIG. 114.—*Complementary Colours overlapping and forming White Light.*

double-refracting spar. The two discs of light projected on to the screen separately are green and red; but when caused to overlap each other by enlarging the aperture through which they pass, the two colours unite in the centre, forming white light, whilst red and green remain intact in those positions which do not overlap. (Fig. 114.)

Other complementary colours would be yellow and indigo, blue and orange.

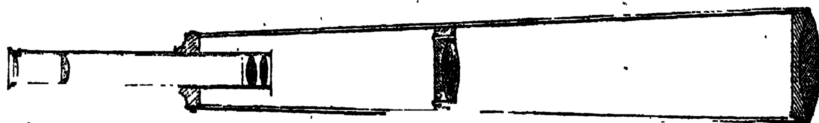


FIG. 115.—*Arrangement of the Composite Lenses in an Achromatic Telescope.*

Flint glass has a greater dispersive power than crown glass; it will spread or disperse the spectrum over a larger space. The dispersive power of the prism used in decomposing light for showing the spectra of incandescent metal is increased by filling them with carbonic disulphide (bisulphide of carbon), and the composition and dispersive powers of the three bodies is as follows:

Crown glass . . .	0·039
Flint glass . . .	0·048
Carbonic disulphide	0·115

THE INTERFERENCE OF LIGHT.

COLOURS OF THIN PLATES.

About the year 1672, Dr. Hook, a very clever mechanician, and learned in all the science of his day, discovered that by splitting mica, which is free from colour, and sometimes used instead of glass, into very thin films, they exhibited the most beautiful colours. But as they were less than the twelve-thousandth part of an inch in thickness, Dr. Hook could not measure them, and was therefore unable to determine the law that regulated the production of any particular colour, according to the thickness of the film of mica. In due course of time the experiments engaged the attention of Sir Isaac Newton, and directly he touched the subject it was truly, so far as intellect was concerned, with the hand of a giant, and he soon discovered a method of measuring the films. He did not begin with mica, because it would have been very troublesome, if not impossible, to split it into a graduated series of films of the extreme thinness required to produce colour. Newton therefore commenced with air, and having once determined the law, it was easy, knowing the index of refraction of all other transparent bodies, to work out by calculation the respective thicknesses required to produce the same colours. He took a plano-convex lens, the radius of whose convexity was 14 ft., and placed it on a double-convex lens, the radius of whose convexity was 50 ft., and by means of proper clamps and screws the surfaces of the two lenses could be brought closely together. The convexity of the lower lens being so extremely slight, it might indeed be almost regarded as a flat surface, like any moderate area on the surface of the globe, because the sphere of glass (of which the lens would be a slice) had a theoretical diameter of 100 ft. (Fig. 116.)

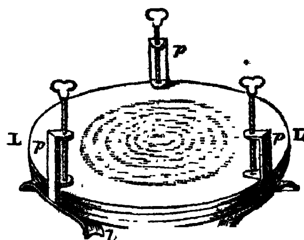


FIG. 116.—*Instrument used by Newton to obtain the Rings of Colour from Thin Plates of Air.*

L L, upper lens pressed on the lower one, *l l*, by the thumb-screws *p p p*.

When the two lenses were pressed together, concentric rays of colour made their appearance; indeed the same kind of effect is often produced accidentally when a number of flat plates of window-glass are piled one above the other, the enclosed air being then pressed by the weight of the superincumbent glass into a film sufficiently thin to show coloured rings.

The Hon. Robert Boyle first discovered that thin bubbles of the essential oils, spirit of wine, turpentine, soap and water, produce the colours, and he

succeeded in blowing glass so thin that, like the mica, it displayed varieties of colour.

Lord Brereton observed the colour of thin oxidized or decomposed films, such as are produced by the action of the weather during a prolonged period on the ancient glass in church windows, or on glass which has been buried in the earth. When steel is tempered, the regular gradations of colour produced by the oxidation of a very thin outer film are a guide to the skilled workman who tempers the metal.

Mr. De la Rue, by floating a very thin film of a quick-drying varnish on the surface of hot water, and then receiving this on a sheet of paper, was enabled to secure in the most perfect manner those lovely tints, which are sometimes associated with the surface of ponds into which greasy matter or oil may pass, or in the puddles after rain in the yard of a gas-works where liquor containing coal oil has been spilt.

The variety of colours which Newton describes in his important "Table of the Colours of thin Plates in Air, Water, and Glass," are given by him in the succession of spectra or order of colours, where he enumerates seven spectra or orders of colours ; these are different from reflected and transmitted rays, and are produced by thicknesses of air, water, or glass, estimated from a scale of an inch divided into one-million parts.



FIG. 117.—*Woodward's Model of Waves, with movable Rods.*

Newton measured the diameter of every coloured ring; he did not depend merely upon calculation, but tried a number of experiments with the colours of the spectra, allowing each to fall separately on his apparatus, and discovered that under these circumstances he no longer obtained a variety of coloured rings, but observed that the central dark spot was surrounded by rings of the same colour as the light incident on the lenses alternating with dark rings.

Thus, supposing Newton to have placed the apparatus for producing the rings into the yellow part of the spectrum, there would be a dark spot in the centre, then a yellow ring, now a dark, again a yellow ring, and so on; he then squared the diameters of the reflected coloured rays, and obtained the odd numbers, 1, 3, 5, 7, 9, &c., while the square of the diameters of the dark rings were as 2, 4, 6, 8, 10, &c. When the rings were observed by transmitted light, the order was reversed—the coloured rings being at the even numbers, and the dark ones at odd integers.

These effects Newton called *fits of transmission* and *fits of reflection* ; they could not be reconciled or explained by his own favourite theory, and, to the honour of this great philosopher, he did not attempt to press the corpuscular theory, and compel it to his own use, but simply left behind him a record of facts, only naming that which he had proved to exist, and giving the relative thicknesses of the plates of air by which each colour is reflected.

The undulatory theory of light alone is adopted to explain these phenomena, and by what is termed the interference of the waves the effects are supposed to be produced. Ingenious models have been made to explain the law of



FIG. 118.—*A Model of Fixed Waves.*

interference; but those of Mr. Charles Woodward, the President of the Islington Scientific Society, are the most simple, and are thus described by him in his admirable little work on the "Polarization of Light:"

A B (Fig. 117) represents a model with rods freely moving in a perpendicular direction through the frame A B, and furnished with pins resting upon the

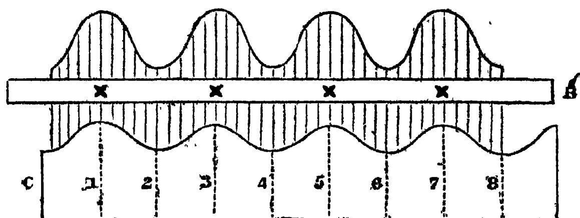


FIG. 119.—*Intensity of Waves doubled by the Superposition and Coincidence of two equal Systems.*

upper part of the frame, so that when at rest the whole may assume the appearance of waves, as in the diagram.

C D (Fig. 118) represents a fixed model with waves of similar size and intensity, and numbered so as to distinguish each half-undulation.

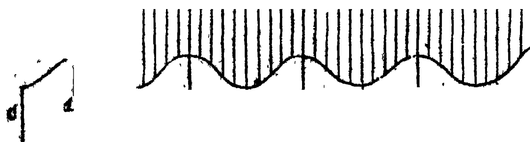


FIG. 120.—*Waves neutralized by the Superposition and Interference of two equal Systems.*

It will be seen that when the stars indicating the highest point of the waves, as A B, correspond with the odd numbers of half-undulations on C D, each system of waves will be in the same state of vibration; and, if so superposed, a series of waves of doubled intensity will be the result, as in Fig. 119.

If, on the other hand, the two systems be so superposed as that the stars on A B shall coincide with the even numbers on C D, as in Fig. 120, there will be a difference of half an undulation in the two systems; the one will neutralize the other by interference, and darkness will be the result.

'If C D be continued so that A B may be moved forward indefinitely, it will be obvious that the waves will be equally increased in intensity by a difference in the two systems of any *even* number, and neutralized by a difference of any *odd* number, of half-undulations. These models are, therefore, well suited to teach matter of fact, viz., that two sets of waves of water may come together and obliterate each other, as in the tides of the port of Batsha, described by Halley and Newton, where the two waves arrive by channels of different lengths, and produce a smooth surface; or two waves of light may come together in such phases that in one case they exalt each other and produce a wave of double intensity, and in the other phase they may destroy one another and cause darkness. A wave of white light is, however, made up of other waves of coloured light; so that when such a complicated series of different-coloured waves interfere, it is easy to perceive that certain coloured waves may coincide and extinguish each other, whilst the remaining colours may unite and intensify each other.

That waves of light do so interfere is placed beyond all doubt by the experiments of Dr. Young, and even more elaborately by the following beautiful experiment devised by Fresnel:

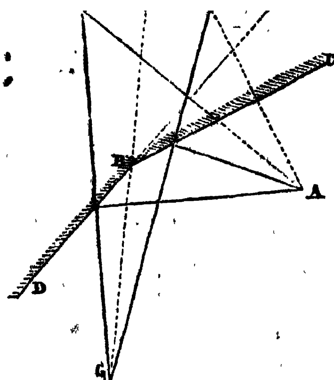


FIG. 121.—*Fresnel's arrangement to show the Interference of the Waves of Light.*

A sunbeam from the Hæliostat is passed through a narrow rectangular slit in the shutter (as described at p. 87), covered with red glass to secure a monochromatic light, or wave of simple light. The red light is brought, by a cylindrical lens of very short focus, to a point at A. The rays cross each other and fall upon two mirrors of parallel glass B C, B D, placed at a very obtuse angle, having their line of intersection parallel to the line of light. After reflection the rays proceed as if they came from the two points F F behind the two mirrors; they interfere at G, and at other points not marked out in the

diagram, and produce light and dark fringes; but, if one of the beams of light proceeding from the points E E be intercepted by a screen, the whole of the alternations of red and dark fringes disappear, and the only light left is that derived from the single ray of red light which remains after the other was removed by the screen. In this diagram two sets of waves only are used, but, of course, the same law applies to all.

It is this principle of interference which produces coloured fringes by inflexion or diffraction, such as rays passing along the edge of a screen, or the fringes at the edge of a plane mirror, or fringes produced by narrow rectangular openings, fringes by two narrow slits very close together, and those obtained through gratings or networks. The word grating might deceive the reader, and lead him to suppose that the effect was caused by some rough arrangement; but these beautiful experiments were carried out by Frauenhofer by tracing parallel lines on a film of gold leaf fixed on a plate of glass, and looking through them with transmitted light. Nature supplies us with striated bodies, which are in effect reflecting gratings. Brewster calculated that there were three thousand lines in an inch of a piece of iridescent mother-of-pearl. But this number has been surpassed by Barton, who ruled from two to ten thousand lines on steel, which he afterwards hardened and used as a die to stamp bright brass buttons. These, when illuminated by the various rays emanating from the numerous lighted wax candles in a ball-room, flashed with the splendid colours of the diamond. The colours of Newton's rings are due to the interference of the light reflected from the upper and under surface of the film of air; for, however thin this may be, it must have an upper and an under surface, like a sheet of paper.

Let Figs. 117 and 118, pages 107, 108, represent two equal systems of waves from red light reflected to the eye from the upper and under surface of Newton's thin plates of air. If they be superposed, as in Fig. 119, page 108, the waves will coincide, and there will be red light, as in the first coloured ring. On moving A B a distance equal to one half-undulation at Fig. 120, the waves will be neutralized by interference, and there will be darkness; on moving A B a second half-undulation, there will be light, and so on; for when the stars indicating the highest part of the waves of A B coincide with the odd numbers of half-undulations of C D, there will be light, as in Fig. 119; and when they coincide with the even numbers, darkness will be caused by interference, as in Fig. 120.

Dr. Young proved that each of Newton's fits of transmission and reflection was equal to half a wave of each colour, and this is *equal in length* to the *thickness of the plate of air* at which that colour is first reflected, and therefore a whole undulation would be equal to two of Newton's spaces or fits, or what he termed the length of an interval between the fits of easy reflection. Thus, the thickness of the plate of air required to produce red light being determined by Newton to be 133 ten-millionths of an inch, double that number or the length of a wave of red light, would be 266 ten-millionths of an inch.

For orange	240	ten-millionths of	an inch
" yellow	227	"	"
" green	211	"	"
" blue	196	"	"
" indigo	185	"	"
" violet	167	"	"

Herschel's table is, perhaps, the most complete record of the invaluable work of Newton. The figures are Newton's, although the meanings of them have been altered to comply with the undulatory theory.

Colours of the Spectrum.	Lengths of an Undulation in parts of an inch.	Number of Undulations in an inch.	Number of Undulations in a second.
Extreme red	0·0000266	37,640	458,000000,000000
Red	0·0000256	39,180	477,000000,000000
Intermediate	0·0000246	40,720	495,000000,000000
Orange	0·0000240	41,610	506,000000,000000
Intermediate	0·0000235	42,510	517,000000,000000
Yellow	0·0000227	44,000	535,000000,000000
Intermediate	0·0000219	45,600	555,000000,000000
Green	0·0000211	47,460	577,000000,000000
Intermediate	0·0000203	49,320	600,000000,000000
Blue	0·0000196	51,110	622,000000,000000
Intermediate	0·0000189	52,910	644,000000,000000
Indigo	0·0000185	54,070	658,000000,000000
Intermediate	0·0000181	55,240	672,000000,000000
Violet	0·0000174	57,490	699,000000,000000
Extreme violet	0·0000167	59,750	727,000000,000000

A very good idea may be given of the effect of the law of interference by means of a simple contrivance proposed by Sir Charles Wheatstone, called the Eidotrope. It is made of two circular pieces of ordinary perforated zinc, one of which is made to turn round in front of the other by means of a band and pulley, the whole being arranged as an ordinary magic-lantern slide. Wire gauze or perforated cardboard may be substituted for the perforated zinc. If the two zinc plates were perforated exactly alike, little or no effect would be observed; but as one set of perforations is always a little in advance of the other, certain shadows, which assume interesting forms, are perceptible when the instrument is used in the magic lantern, and the figures projected on to the disc. The dark shadows are caused by the mechanical interference of the zinc plates in the proportion to represent the half-undulation, and in some positions are very distinct. If wire gauze is employed, the shadows assume just the same appearance as the surface of watered silk.

DOUBLE REFRACTION AND THE POLARIZATION OF LIGHT.

When a ray of light falls upon the surface of Iceland spar, it is divided into two colourless rays, one of which is called the ordinary, and the other extraordinary, ray of light; both rays possess physical properties different from those which belong to common light, and if reunited they would again form common light.

In the year 1817, Dr. Young, the famous revivalist and supporter of the undulatory theory, whilst considering the results of the speculations of

Huygens, Wollaston, and Brewster, and the cause of double refraction, was led to believe that the effect must arise from a difference of elasticity in the crystal of Iceland spar; and being aware that Newton had expressed the idea that a ray of light possesses *sides*, he first proposed the hypothesis of transversal vibrations of light. The theory is, that in the progress of a ray of light the forward motion is made up of two sets of vibrations, which are either longitudinal or transversal. The longitudinal vibrations represent the path or direction of the ray, whilst the transversal ones take place at right angles to the former. This peculiar motion may be compared to the particles of water which move up and down whilst the wave advances horizontally. Dr. Young illustrated these vibrations by the propagation of undulations along a stretched

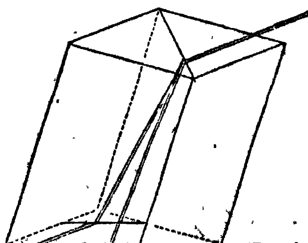


FIG. 122.—*A Rhomb of Iceland Spar, showing the double Refraction of Light*

cord agitated at one end, which supposing a person to hold in his hand, and by moving first quickly up and down, a wave will be produced, that will run along the cord (see p. 6) to the other end, and then by a similar movement but from the right side to the left, another wave will be produced, which will run along the cord as the former; but the vibrations and undulations of each will be in planes at right angles to each other, and independent of each other



FIG. 123.

A, Woodward's cardboard model representing a ray of common light; B, transverse section, showing the figure of a cross.

one being in a perpendicular plane and the other in a horizontal plane, so that according to this theory, A (Fig. 123) may be considered to represent a ray of ordinary or unpolarized light, a cross section of which would give the simple figure B, it being understood that the vibrations take place in planes all round the direction of propagation.

With the help of this hypothesis of transversal vibration, double refraction is easily explained, and is put into the most concise terms by the editor of

the late Dr. Young's lectures: "A ray of light falls on the surface of a crystal the elasticity of which is different in different directions. The motions consequently are not all transmitted with the same velocity, and, as the index of refraction depends on the velocity, one set of vibrations will, on emergence, be totally separated from another. Moreover, the light, on emerging, is quite different from common light. In each ray it consists only of vibrations in one direction. Suppose, therefore, one of these rays to fall on a second crystal placed in a similar position with the first; it will not now be divided into two, but will emerge just as it entered. Light which consists of vibrations in one direction is called polarized light. In 1810 it was discovered by Malus, an officer in the French engineers, that light reflected from the same face of unsilvered glass is more or less polarized, and Brewster ascertained that it is perfectly so when the tangent of the angle of incidence is equal to the refractive index, and also that the transmitted ray is partially polarized."

But why called polarized? The term, perhaps, is not a very happy one, but was suggested by analogy to the poles of a magnet.

Dr. Whewell thus defines polarity: "Opposite properties in opposite directions, so exactly equal as to be capable of accurately neutralizing one another."

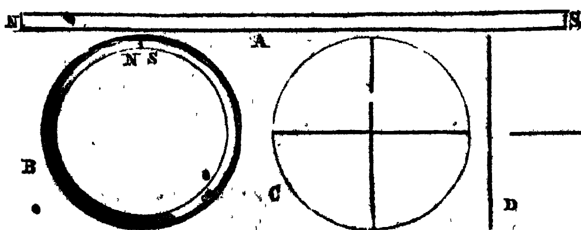


FIG. 124.

A, magnet made of watch-spring with north and south poles; B, same magnet bent round, and polarity neutralized; C, common light; D D, polarized light.

A piece of steel watch-spring, when magnetized, has a north and south pole (see A, Fig. 124); but when the same piece of steel is bent round in a circle, as at B, Fig. 124, the two forces neutralize each other, and the polarity is gone. Such a circular piece of steel might be compared to common light: it is like the section of a hoop-stick, C; whilst polarized light may be compared to the straight steel magnet A, or to a lath. A hoop-stick is the same all round; but a lath has a top and bottom and sides. The former may represent common light, and the latter polarized light; and thus polarization is simply the separation of the two sets of undulations or vibrations, D D, Fig. 124.

When common light is passed through transparent refracting bodies perfectly homogeneous in their structure, and of a uniform temperature throughout, such as gases, common air, pure water, annealed glass, jelly, and many kinds of crystallized bodies, the form of whose primitive crystal is the cube, the regular octahedron, and the rhomboidal dodecahedron, such as alum, common salt, or fluor spar, the beam of light is refracted singly; but in nearly every other crystalline body the rays undergo double refraction, and, although this is not apparent at once, like it is with Iceland spar, the property of double refraction is soon discovered by using polarized light.

Polarized light may be obtained in four different ways, viz.—

Firstly, by reflection;

Secondly, by simple refraction;

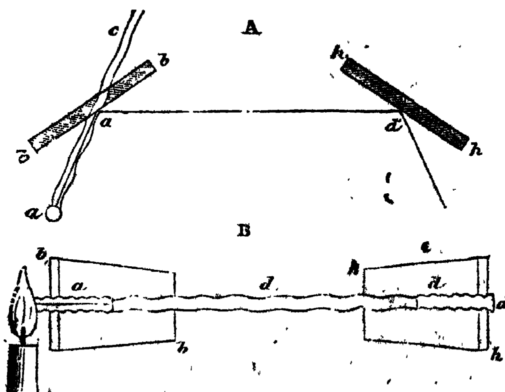
Thirdly, double refraction;

Fourthly, by transmission through a plate of tourmaline, slit parallel to the axis of the crystal.

Thirty years ago, Mr. J. F. Goddard, then of the Polytechnic, London, received from the Society of Arts a silver medal for his apparatus for experiments on polarizing light. The description which accompanied the apparatus is so good and so little known, that the writer has quoted the most important part of it, in order to explain, with the assistance of the apparatus invented by Mr. Goddard, this most difficult branch of optical science.

POLARIZATION BY REFLECTION AND SIMPLE REFRACTION.

"Polarization may be effected with common crown glass, either by ordinary reflection or refraction, each of which will exhibit the same effects. In order to understand this, let *b b* (Fig. A 125) represent a bundle of plates of common



FIGS. A and B, 125.—*Explanation of Polarization by Reflection and Simple Refraction.*

glass, placed so that a ray of ordinary light, *a a*, may form an angle of incidence of 56° 45′ with a line perpendicular to their surface; then the light reflected and represented as passing off at *a* will be polarized light; and if a proper number of plates, which for the same angle of incidence is twenty-seven, be employed, the light transmitted at *c* will be polarized also, the two rays possessing the same properties, but at right angles to each other.

"Thus in the reflected ray *d* the vibrations are supposed to take place in a perpendicular plane, this being a bird's-eye view (Fig. B 125 being a horizontal view of the same thing), whilst in the refracted ray *c* the vibrations are performed in a horizontal plane. This will be easily understood on analyzing either of the rays, which may be done by the same means as that by which the original beam is polarized. Thus, supposing we experiment with, test, or

analyze the reflected ray *d*, in which the vibrations are in a perpendicular plane, when it is made to fall upon a second bundle of glass, *h h*, at the same angle of incidence, and the glass be so placed that the reflection may again be in the same plane, it will be again wholly reflected, as at *d′ d′*, and none will be transmitted or refracted through the second bundle of glass, for the very same cause that produced its reflection from the first bundle, viz., that the vibrations continue parallel to the reflecting surfaces. But if the second bundle of glass is put in such a position that the vibration shall be performed in a plane perpendicular to the reflecting surface (which may be done by turning it round 90° in such a direction that the ray of light shall be the axis on which it turns, and always making the same angle of incidence), then, as soon as it begins to turn, the reflected light will begin to deercase in intensity, and, as it decreases, a portion will begin to be transmitted or refracted through the glass, which will increase in the same ratio as the reflected light decreases; and when the bundle of glass has turned 90°, in which position it is shown at

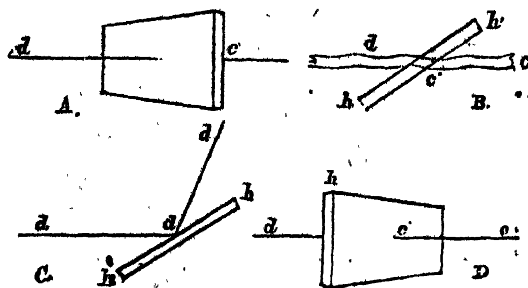


FIG. 126.

A, Fig. 126, as a bird's-eye view, and at the horizontal view, B, Fig. 126, the light *d* is wholly transmitted or refracted at *c′ c′*, no portion being reflected. In such a position the vibrations will be in a plane perpendicular to the reflecting surface; and such vibrations are always transmitted, and not reflected, as we also see has taken place in the polarization of the original beam of common light at A, Fig. 125, before referred to. Now let the second bundle *h h*, B, Fig. 126, continue to turn; it will be seen that, as soon as it begins to move, the transmitted *c′ c′* will begin to decrease, a portion beginning to be again reflected, which, as the glass turns, will increase in intensity in the same ratio as the transmitted light decreases, until it has turned another 90°, or reached 180° from the first position, as seen at C, Fig. 126, when the plane of reflection is again parallel to the plane in which the vibration takes place; consequently the whole light is again reflected at *d′ d′*, none being transmitted, from the same reason as before stated. On continuing the revolution, the same thing occurs at each quadrant of the circle. In Fig. D 126 the bundle of glass *h h* is represented as having turned 270°, or three-quarters of a circle, in which position the same thing occurs at 90°, when the light *d* is wholly refracted and transmitted through glass, as at *c′ c′*; so that it is evident, in these experiments, that there are two positions, shown in Figs. 125 and 126, in which the same ray of polarized light *d* is wholly reflected, as at *d′ d′*, and two other positions, A, D, Figs. 125 and 126, in

which it is wholly transmitted by the analyzing bundle of glass, as at $c' c'$, all of which are easily understood by bearing in mind the description of the physical nature of common light according to the undulatory theory, and the action of the first or polarizing bundle of glass, or transversal vibrations.

"Thus we obtain experimental data, which may be expressed as follows:

COMMON LIGHT

1. Is capable of *reflection* at oblique angles of incidence in *every position* of the reflector.

2. Will pass through a bundle of plates of glass in any position in which they may be placed.

3. Passes through a plate of tourmaline, cut parallel to the axis of the crystal, in every position of the plate.

POLARIZED LIGHT

1. Is capable of *reflection* at oblique angles of incidence *in certain positions only* of the reflector.

2. Will pass through a bundle of plates of glass only when they are placed in certain positions.

3. Does not pass through a plate of tourmaline cut parallel to the axis of the crystal, except in certain positions; in others, the tourmaline, though quite transparent, stops the whole of the polarized light as if it was opaque.

"A bundle of plates of glass or a slice of tourmaline is consequently to be regarded as a test of polarized light, and enables the physicist to distinguish between the latter and common light, which he is said to analyze, the bundle of glass or the tourmaline being called *the analyzer*.

POLARIZATION BY THE TOURMALINE.

"Amongst crystallized minerals there are many possessing the property of polarizing the light transmitted through them, the most remarkable of which, however, is the tourmaline. This mineral crystallizes in long prisms, whose primitive form is the obtuse rhomboid, having the axis parallel to the axis of the prism.

"It must be remembered also that the axis of crystals is not, like the axis of the earth, a single line within the crystal, but a *single direction* through the crystal; for supposing Fig. 127 to represent a crystal of any kind, the axis of

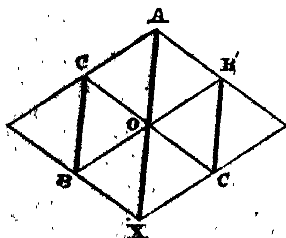


FIG. 127.

FIG. 128.

A, single plate of tourmaline; B, superposition of the second plate on the first.

which is in the direction A X, if we divide such a crystal into four along the lines B B and C C, each separately will have its axis A O, O X, C B, and B C, which, when united in one crystal, are all parallel; every line, then, within the crystal parallel to A X is an axis.

"If we cut a crystal of tourmaline of a proper kind parallel to the axis into thin plates of an uniform thickness (about one-twentieth of an inch), and polish each side, it possesses the property of polarizing light transmitted through it in a remarkable manner. Fig. A 128 represents one of these plates, the lines across which we may suppose to be parallel to the axis. Now, if we hold such a plate before the eye, and look at the light of the sun, or flame of a candle, or any artificial light, a great portion will be transmitted through the plate, which will appear quite transparent, having only the accidental colour of the crystal, which in specimens suited for these experiments is generally *brown* or *green;* but the light so transmitted will be polarized light, and, on being *analyzed* by a second plate, which may be done by looking through both at the same time, we shall find that when the axes of both plates coincide, *i.e.*, are parallel with each other, the light which is passed through the first will also freely pass through the second, and they will together appear perfectly transparent; but when one is turned round, so that the axes of each plate are at right angles (across each other), as represented in B, Fig. 128, not a ray of light will pass through—they will appear perfectly opaque, although we may be looking at the meridian sun. If we suppose the structure of the crystal to be represented by a grating, the bars of which are the axis, we may conceive that its action on ordinary light will be to transmit such vibrations only as are performed in a plane parallel with the axis, and to stop all others. Hence, the light transmitted through a single plate will be polarized, and possess exactly the same properties as the light polarized by any other means, as may be proved by analyzing it by any of the means which have been described. But let us suppose a second tourmaline to be used, and, as it is understood that in the light which makes its way through the first tourmaline the vibrations are parallel to the axis, all other vibrations being stopped when the axis of the second or analyzing plate is perpendicular to the first, as represented in B, Fig. 128, the vibrations which have passed through the first, being now perpendicular to the second, will also now be stopped by the second plate in such a position; and, as it is turned round, there will be found two positions in which it will not pass through, being wholly stopped, these positions being at right angles to each other, as will be understood by B, Fig. 128, where *a a* is the first or polarizing plate, and *c* the second or analyzing plate, overlapping the first."

Mr. Goddard then describes the instrument for which he received the silver medal—the oxy-hydrogen polariscope. (Fig. 129.)

"In this instrument A represents the hydro-oxygen blowpipe; B, the lime cylinder and diverging rays of light refracted by the condensing lenses *c c c* and falling upon a mirror *b b*, composed of ten plates of thin flattened crown glass placed in the elbow of a tube bent to the polarizing angle of crown glass; *d*, converging rays of polarized light reflected from the mirror; *h h*, a bundle of sixteen plates of mica, for analyzing the light previously polarized by reflection; *c*, a double-refracting crystal (film of selenite) placed in the focus of the object-glass I, which forms an image of the crystal upon a disc or screen at *r*. As the analyzing bundle of mica, *h h*, is made to revolve (or turn round), the image of the selenite upon the disc undergoes all the changes, and exhibits alternately the primary and complementary colours *at the same time*, one being reflected in the direction *s*, and the other transmitted and seen at *r*.

"The great advantage of polarizing the light from a number of plates is the obtaining a beam of any required dimensions, of much greater intensity than

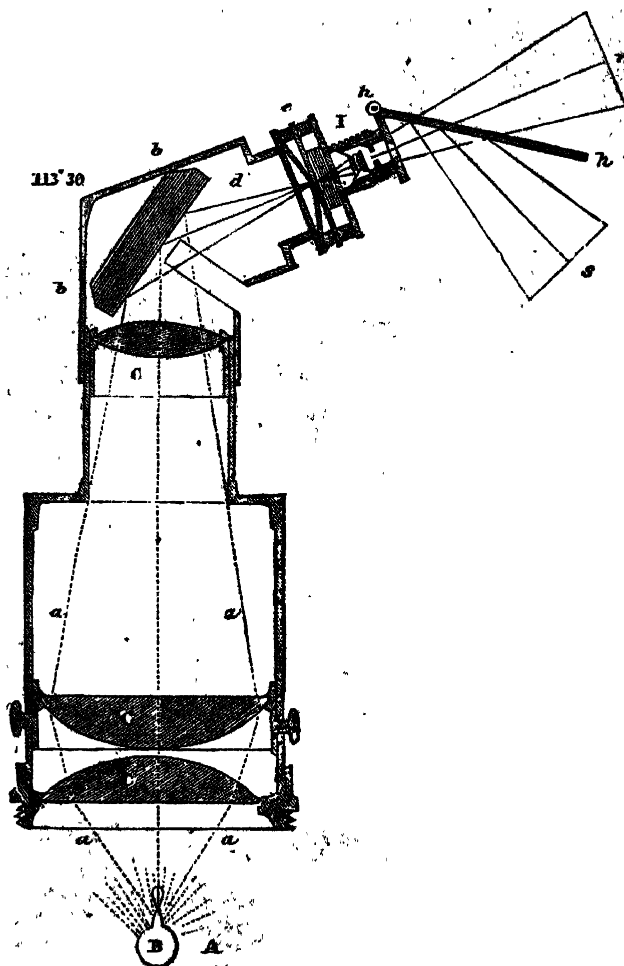


FIG. 129.—*Goddard's Oxy-hydroge*

by any other means; for whatever single surface may be employed that polarizes light at the same angle as the glass used (which for crown glass is 56° 45′), we obtain an additional quantity by laying on it a single plate of such glass, and a further quantity by the addition of a second, third, or any further number; the quantity of light added by each succeeding plate being, however, less in proportion to the number of plates through which it has previously to pass. In this respect the single-image (Nicol's) prism of Iceland spar is decidedly the best for analyzing, as by this a great variety of objects may be exhibited. Its application is shown in Fig. 130, where *e*, the selenite,

is placed in the rays, *d d d*, of polarized light, an image of which is projected by the lenses; *h* is the analyzing prism through which the rays of light *r r* are refracted.

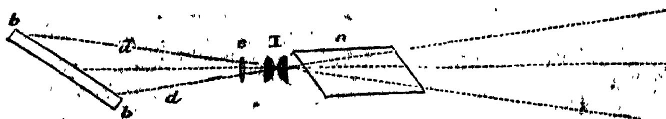


FIG. 130.—*Use of the Nicol's Prism as an analyzer.*

"But there is one class of phenomena, viz., the rings seen to encircle the optic axes of crystals, the number of which increases in some crystals (the topaz, for instance) with the divergence of the rays of polarized light passing through them. It will be evident, then, that the tourmalines enable us to exhibit more of these rings, and upon a larger scale, than the prism, which will be better understood by the arrangement shown in Fig. 131.

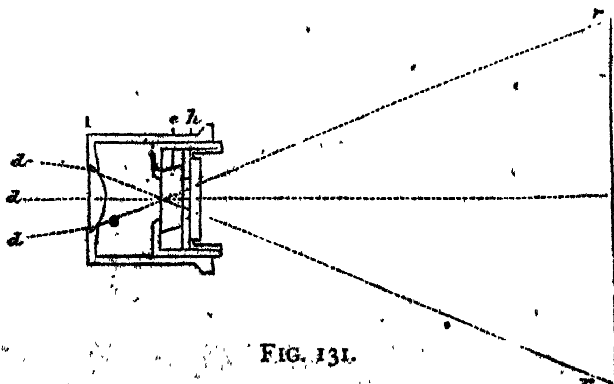


FIG. 131.

"*d d d*, converging rays of light polarized by reflection; *l*, a lens of short focus transmitting a cone of light with an angle of divergence from its ray *r r* of 45°; *e*, a crystal, say topaz; *h*, the tourmalines for analyzing; so that, even for these purposes, the cost of the tourmalines is reduced one-half by Goddard's polariscope, as only one need be used."

The writer frequently uses Goddard's instrument as made by Mr. Darker, jun., of Paradise Street, Lambeth, whose father before him earned so much credit in the practical parts of this branch of optics. Darker also makes the most elaborate and beautiful designs in selenite or sparry gypsum, being the native crystallized hydrated sulphate of lime, from which plaster of paris can be made by driving off the water of crystallization. This mineral, split into thin films, and cut under water, or oil, or turpentine, is laid upon glass with Canada balsam. The greatest nicety is required in the manufacture of the selenite slides, or else all the edges of the figures would be rough.

A piece or film of selenite of unequal thicknesses exhibits the most varied and beautiful colours when placed in the polariscope, the colours transmitted by the analyzer being complementary to those reflected from the bundle of glass plates. Any transparent substance in which unequal elasticities occur will present phenomena of colour when placed in the polariscope. A piece of plate glass, if well annealed, shows no colour until it is bent or squeezed by being placed in a strong frame provided with a screw.

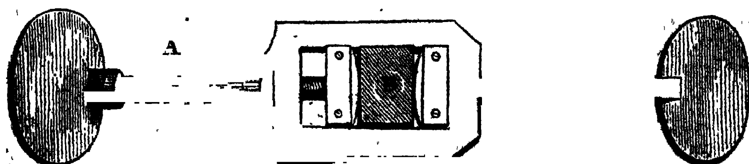


FIG. 132.—*Apparatus for compressing Glass.*
A A, the press; B, the piece of plate-glass.

On the same principle, unannealed glass exhibits some of the most vivid colours and figures. (Fig. 133.)

Or if a rod of plate glass is placed in the polariscope and heated with a



FIG. 133.—*Unannealed Glass.*

red-hot copper bar, the unequal expansion of the particles causes that retardation in the path of the rays which results in interference, and the production of colours, and these disappear gradually when the hot copper bar is removed. A little jelly allowed to solidify in a proper frame, the sides of which are of glass, exhibits no double refracting power until it is subjected to pressure.

A quill pen flattened out and arranged for exhibition in the polariscope will give some very pleasing tints.

Water of an uniform temperature has no double refracting power, but when frozen and converted into ice the particles exhibit unequal elasticities, and colour is the result when it is placed in the polariscope.

If plates of selenite or any doubly refracting crystal of considerable thickness be ground away on one edge, so as to give them a wedge-shape, they will present bands or fringes composed of all the colours of Newton's table, arising from the various thicknesses which such a shape possesses; or by grinding a concavity in a similar plate a number of concentric rings (reminding

the spectator of Newton's rings) are produced. Small crystals obtained by evaporating single drops of solutions of acetate of zinc, chlorate of potash, sulphate of soda, oxalic acid, oxalate of ammonia, sulphate of copper, borax, ferrocyanide of potassium, &c., may be exhibited in the polariscope.

The lovely rings obtained by using uniaxial and biaxial crystals are well shown by Goddard's apparatus, with a large Nicol's prism or a good tourmaline as the analyzer. To exhibit these coloured rings a higher microscopic power

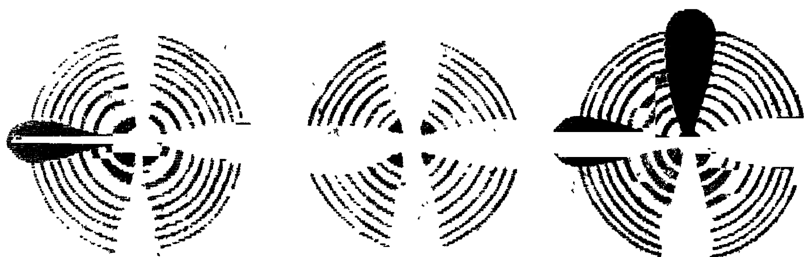


FIG. 134.

Appearance of the rings produced by Iceland spar cut perpendicularly to the principal or shortest axis, and alternate appearance of the black and white cross with complementary colours, as the analyzer is rotated.

is used. This is always supplied with the instrument, and is put on before using the polariscope. For these experiments Iceland spar, rock crystal, emerald, sapphire, beryl, ice, furnish good examples of uniaxial crystals.

A very large number of crystals are biaxial, and have two axes of double

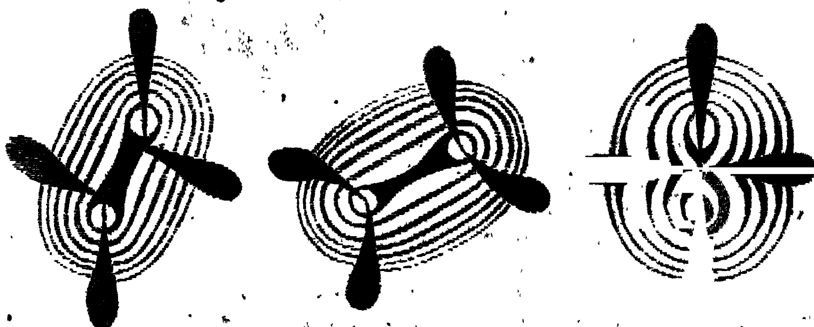


FIG. 135.

Double curves or sets of elliptical or oval-like rings produced by a plate of nitre 1-12 or 1-15 in. thick, cut perpendicular to the prismatic axis.

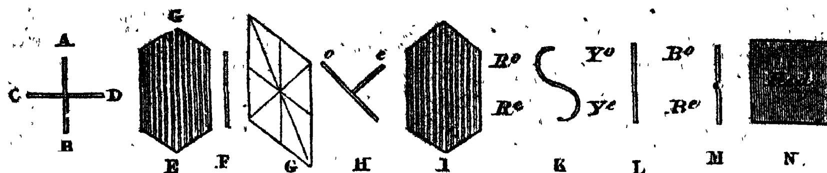
refraction, which are more or less inclined to each other. These are termed biaxial crystals, or crystals with two optic axes. Nitrate of potash exhibits this optical property very perfectly, also Rochelle salt, selenite, sugar, borax, and many others.

The coloured bands obtained from biaxial crystals are not concentric, but somewhat oval, with two centres, which represent the two axes of the crystal.

The splendid phenomena of colours produced by various substances in polarized light are the results of transversal vibrations. When a single wave or vibration in any one plane is divided into two, at right angles to each other, one will of necessity be half a wave behind the other, the two being opposite halves of the same wave; and as each of these again is divided or resolved into two others, there will be four waves or vibrations produced from the original one. Two of these in one plane coincide and strengthen each other, while the two in the other plane oppose and destroy each other.

This difficult subject may be summed up and concluded with Woodward's very instructive diagrams, exhibiting at one view

POLARIZATION,
ANALYZATION,
INTERFERENCE OF LIGHT.



FIGS. 136, 137.

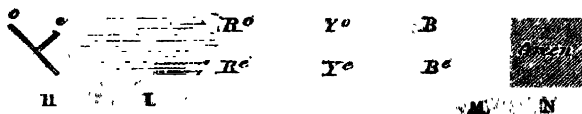
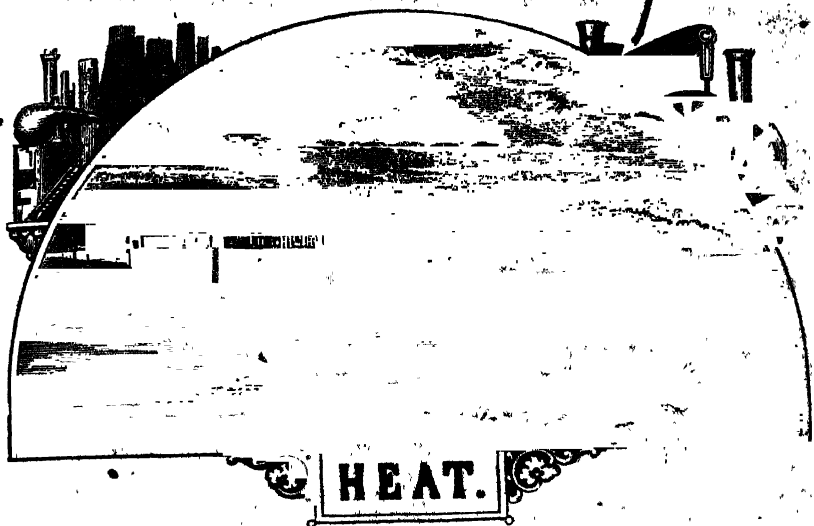


FIG. 136.—A, B, C, D, common light; E a plate of tourmaline, or a bundle of plates of glass, termed the polarizer; F, polarized light; G, a plate of selenite; H, dipolarised light; I, a plate of tourmaline, or a bundle of thin plates of glass, called the analyzer; K, coincidence of waves for red light; L, interference of waves for yellow, and M of those for blue light; N, the result—red light.

FIG. 137.—I, the analyzer turned round 90°; K, interference of waves for red light; L, coincidence of waves for yellow, and M, those for blue light; N, the result—green light.



HEAT.

THERMOMETRIC HEAT.

AMONGST the physical forces, the corellation of which has been so well discussed by various philosophers, that termed *caloric* (at one time, like light, considered to be a direct emanation of some rare and subtle form of matter) has received the most careful attention. Light is discoverable by two most sensitive inlets—the eyes. The sensation termed heat is not more appreciable by the eyes than by any other part of the human body, and yet the mind may be easily deceived by sensations caused by heat or its absence, termed cold. The body may experience the greatest torture by an excess of heat or burning, and it may derive pleasure from the application of a moderate amount of the same power, as in the use of the Turkish or other baths.

The nervous system distributed over the surface of the body cannot, however, distinguish properly degrees of heat, and we seem to be able to discover only when heat is entering or leaving our bodies, and then the exclamations referring to extremes, such as "how hot!" or, "how cold!" escape us. And even this faculty is limited, because the sensations caused by touching a lump of frozen mercury and a hot iron are the same. The unfortunate person who does this will complain as if he were burnt with the intense cold of solid mercury. We cannot, as with the eye or the ear with light and sound, discern gradations of heat; hence artificial means have been invented to supply this want.

It is not surprising that heat should have been considered to be a material body, entering into combination with solids, fluids, or gases, because it is so

readily evoked from ponderable substances. A clever blacksmith, with his hammer, anvil, and a rod of good iron, will dexterously obtain, by hammering the metal, enough heat to light his forge fire, provided a little sulphur is used as the intermediate combustible body.

Heat travels with light from the sun; and as Newton succeeded in convincing his contemporaries that the latter was a material body, it came to pass by a natural sequence of reasoning that the former should also be regarded as a subtile rare form of matter opposed to cohesion. The material theory of caloric—the hypothesis of "emission"—has given way to the more rational theory of "undulation." If, as has been explained at p. 1, an imponderable elastic *ether* pervades all space, a peculiar vibratory motion set up in the material particles of a body may be communicated to this ether; and then, on the same principle that a glass trembles whilst producing sound in air, so the minute particles or molecules of solid fluids or gases oscillate, and these oscillations or vibrations are communicated to and transmitted by the ether. Physicists, however, prefer to speak of their favourite hypothesis as "The Dynamical Theory" (δυναμις, power). The title at once shows that heat, and not light, is intended to be expressed. Heat is in every sense of the word a "power;" the terms are mutually convertible the one into the other. The combustion of coal produces heat, which generates steam, and the latter is the greatest modern representative of power.

Power, as shown by the muscular force of the arm conveyed through a hammer, generates heat when metals are beaten on the anvil. This connection between heat and power is shown in the most perfect and masterly style by Dr. Tyndall,* the industrious and worthy successor of Faraday. He has enriched this branch of philosophy with a vast number of practical demonstrations and experiments, giving quite a new and fresh appearance to a science which seemed to have reached its limits in the stereotyped repetition of descriptions of thermometers, pyrometers, calorimeters, and eternal disquisitions on specific heat and latent caloric. Referring back to heat as the equivalent for power, there is a telling experiment of Tyndall's, in which a brass tube containing water is connected with a whirling table, and whilst it is going round with great velocity, it is rubbed with the wood of a lemon-squeezer; the friction soon generates enough heat to cause the water to boil, and to eject a cork with which the tube is closed. Power generates heat, and *vice versâ*. If a moderate-sized piece of lecture-table apparatus generating heat is to be regarded as a power, what must be the energy of the sun? what kind of force is at work to produce so much heat? Pouillet has carefully ascertained the total heating effect of the sun's rays upon the earth, and estimating the whole heating power of the sun as 2,300 millions of parts, he calculates that less than one of those parts only reaches our earth, and yet it would melt a layer of ice thirty-five yards thick over the whole surface of our globe. This proportion of heat is not all available: some of it is at once converted into power by setting the air in motion, to create the winds; another portion raises the water of the ocean into vapour, which, descending in the form of rain on high levels such as the mighty water-shed which supplies the great lakes (discovered by Speke and Grant and Sir Samuel Baker), the sources of the Nile, flows down to the lowlands, giving rise to water power, which is again the equivalent for

* Heat Considered as a Mode of Motion. By John Tyndall, F.R.S., etc. Longman, Green, Longman, Roberts, and Green.

heat; another part stimulates and increases the growth of plants; and thus, in ages long since passed away, the heat of the sun's rays was not all lost, as the older Stephenson insisted, but stored up ready for man to use in another form, viz., coal, and therefore called potential heat. The plants, being the food of animals, again contribute to the production of animal heat and muscular force. The sources of heat are all connected with motion of some kind.

No. 1. *Friction* is a notable illustration, and it was by causing two pieces of ice to rub one against the other that Sir Humphrey Davy *generated* heat, liquified the ice; and like Dr. Young, who proved that light could turn a corner, and established by his experiments with inflection a sort of basis upon which the undulatory theory of light was again reconstructed, so this famous experiment of Davy supplied a great fact, and gave the first blow to the old theory which said that the ice melted because latent heat was made sensible heat, when it was well known that water at a temperature of 32° Fahrenheit contains much more heat than ice; how, then, could the ice, already deficient in heat, supply enough to satisfy the condition of water? There are plenty of illustrations of the generation of heat by friction. The flint and steel; the attrition of dried wood, as used by savage tribes; the famous experiments of Count Rumford whilst boring cannon, when enough heat was generated in two hours and a half to cause two and a half gallons of water to boil; the friction of railway-wheel axles, which have been known to become red hot and to set fire to the woodwork of the carriage. In North America, a case is quoted where heat was intentionally generated by waste water power and used for heating purposes, the generator being two flat plates of iron which rubbed against each other.

No. 2. *Percussion.*—It was said formerly that metals when struck with a hammer, or with a die in the coining-press, became hot because their density was increased, and therefore their capacity or containing power for heat was altered; but it is clearly shown that this is not the true explanation. Lead, for instance, which becomes hot by percussion, does not increase in density and yet becomes hot—so hot that when projected from the steam gun in the form of bullets against a wrought-iron target, a flash of light is apparent in a darkened room. The heavy shot used for battering iron plates always become very hot after they have struck the plate.

No. 3. *Chemical Action.*—The bringing together of a number of atoms, however small, the clashing together (as Tyndall calls it) of particles to produce new compounds, as in the heating and combustion of finely powdered antimony when it is brought in contact with chlorine gas, or the heat generated by combustion or from other chemical changes, are all to be regarded as the result of motion which the eye cannot detect, but which must occur before the elements come in contact, combine, and form new compounds. There are many chemical changes accelerated by motion, and hence the stirring-rod is an important mechanical means to secure the more rapid union of particles.

No. 4. *Electrical Action.*—The very essence of the existence of electrical power is circulation or motion. The intense heat generated by the discharge of a powerful Leyden battery through a thin iron wire seems to be increased by the resistance offered to the passage of the current, and thus work is consumed. The ignition of a platinum wire by a current of voltaic electricity affords a further instance of resistance; whilst another wire of the same size made of silver, offering less resistance and consuming less work, does not become red hot. We speak of a current of electricity: a current is something

flowing; it is of course motion. Here again the two forces are similarly convertible. The heat generated by the passage of a current of electricity through a platinum wire will set up another current of electricity, if the heat is applied to a series of bars of bismuth and antimony arranged properly, and thus called a thermo-battery or multiplier—a most delicate indicator of heat, which in connection with the galvanic needle is usefully and extensively employed in experiments where heat, inappreciable by a thermometer or other ordinary means, is generated.

No. 5. *Vital Power*, impossible without food, appears to be the result of a kind of slow combustion, or change of carbon and hydrogen into carbonic acid and water, and furnishes another illustration of heat generated by chemical action. The muscular power of a horse, as sagaciously observed by Count Rumford, might certainly be used to produce by friction (as in the boring of iron) enough heat to cause water to boil for the purpose of cooking victuals, if a quicker and more advantageous mode were not suggested by the direct combustion of the fodder which the horse must eat to maintain the animal heat, in order to be able to exert his muscular energy.

To work out the relation between heat and mechanical power, it has been found necessary to establish a standard of comparison, or unit of work, which latter in England is defined to be "the force required to overcome the pressure of one pound through the space of one foot."

By a very extensive series of experiments Dr. J. P. Joule determined that 772 foot-pounds, or units of work, have to be performed to raise a pound of water at about 50° Fahrenheit one degree; 772 units of work would, therefore, be called the mechanical equivalent of heat, and an equivalent to a force that would raise one pound 772 feet high; or, if we reverse the statement, and imagine the same water falling through 772 feet, it would be raised one degree Fahrenheit. The power or force used was measured by the descent of weights, which caused the apparatus, *viz.*, an iron paddle-wheel, to rotate in water or mercury, and, by the friction of the iron and mercury or water, to eliminate heat, which was estimated in the most careful manner. "Joule's equivalent" is, therefore, a standard of the most valuable and truthful kind, verified by another great man, Dr. Mayer, who, by different means and by calculation, makes out the equivalent to be 771·4 foot-pounds, instead of 772, and thus proved how correct had been the previous experiments and calculations of Joule.

Dr. Young says, "If heat is not a substance, it must be a quality; and *this quality can only be motion*. It was Newton's opinion that heat consists in a minute vibratory motion of the particles of bodies, and that this motion is communicated through an apparent vacuum by the undulations of an elastic medium which is also concerned in the phenomena of light. It is easy to imagine that such vibrations may be excited in the component parts of bodies by percussion by friction, or by the destruction of the equilibrium of cohesion and repulsion and by a change of the conditions on which it may be restored in consequence of combustion or of any other chemical change." Further on, he says, "The effect of radiant heat in raising the temperature of a body on which it falls resembles the sympathetic agitation of a string, when the sound of another string, which is in unison with it, is transmitted to it through the air.

"All these analogies are certainly favourable to the opinion of the vibratory nature of heat, which has been sufficiently sanctioned by the authority of the greatest philosophers of past times and of the most sober reasoners of th

present. Those, however, who look up with unqualified reverence to the dogmas of the modern school of chemistry will probably long retain a partiality for the convenient, but superficial and inaccurate, modes of reasoning which have been founded on the favourite hypothesis of the existence of caloric as a separate substance; but it may be presumed that in the end a careful and repeated examination of the facts which have been adduced in confutation of that system will make a sufficient impression on the minds of the cultivators of chemistry to induce them to listen to a less objectionable theory."

These anticipations of Young have been fulfilled: the re-establishment of the undulatory theory of light, by his exertions, has been slowly followed by the reception of the dynamical theory of heat.

THE COMMON EFFECTS OF HEAT.

When a solid is raised in temperature, either by percussion or by the direct application of heat, the vibratory motion supposed to be set up in the molecules or atoms of the substance appears to overcome for a time their cohesive force, and they are separated: they occupy more space; they expand, and, imperceptible as that expansion must be to the eye, it may still be made apparent by a proper instrument. A miniature house, fitted with a number of movable metallic tiles, is so arranged that, when the outer walls are driven apart by any means, the roof and tiles fall in. Between the parts of the model representing the walls of the house is arranged a broad band of brass, which is nicely adjusted by a screw, so that it just touches the sides, which are held together with a spring. When a series of spirit-lamps are lighted under the bar, it

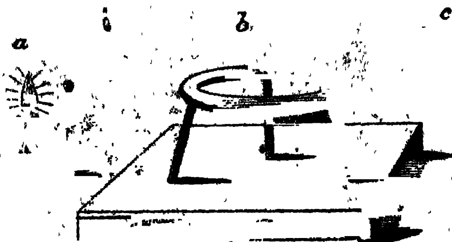


FIG. 138.

a, the spirit-lamp; *b*, the brass ring; *c*, the brass ball.

soon expands with great force, and, overcoming the springs which hold the sides together, they are pushed out, and the rattle of the falling roof and tiles shows to the eyes and ears the catastrophe that might happen on a larger scale. The expansion of the brass rod is thus indicated in a simple and effective manner. When the contents of warehouses provided with great iron girders take fire, the latter expand, push out the walls, and ultimately bend themselves (when they become red hot) with the superincumbent weight above them.

What is called Gavesande's ball (Fig. 138) is a simple and effective mode of showing cubical expansion. A brass ball is carefully turned and polished, so that it exactly fits, and will pass through a metal ring; but, when heated,

expansion takes place, and, instead of falling through the ring, it is held up as in a ring-stand, and will no longer pass through the opening.

The expansion of a fluid body is also shown by placing some coloured water in a flask; to this is fitted a cork and tube with a small bore, which is bent round at the top, so that any liquid ejected by expansion may fall into a shallow dish containing some bits of potassium; the rise of the liquid in the tube may be watched by placing a piece of cardboard behind it, and directly the full expansion occurs the liquid is ejected and the potassium takes fire.

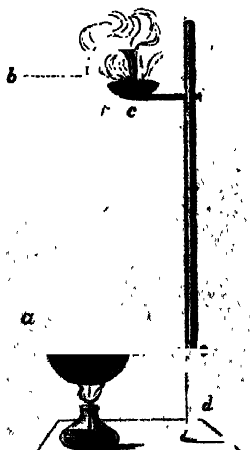


FIG. 139.
1, the flask with cork and tube, filled with water coloured with ink or solution of indigo to the point b; c, cup containing the potassium; d, the ring-stand and spirit-lamp.

The expansion of gases by heat is readily shown by various simple experiments. The neck of an empty retort is placed under water, and directly the body is heated the air expands and passes in bubbles through the water; before removing the lamp a little ink should be stirred into the water, so that when the heat is withdrawn the amount of expansion may be shown by the rise of the coloured water to fill the space at first occupied with air, but now lost by expansion.

The Montgolfier or fire-balloon has never ceased to please, because its inflation is so simple and rapid. The only difficulty seems to be to avoid setting the paper on fire; this is easily prevented by using a metal funnel with coarse wire gauze at the top, and inside of which the large piece of tow, wetted with spirits of wine, is allowed to burn; the inverted funnel may be supported on three legs, and the mouth should be at least 3 in. in diameter, in order to allow the heated air to pass rapidly into the paper bag. By attaching a thin string, the balloon may be let up and down any number of times. When the balloon is intended for the amusement of young people, at an out-door *fête*, the balloon can be sheltered from the wind by a blanket stretched between two poles; and if the balloon, when nearly ready to start, is blown by a sudden gust of wind across the heating apparatus, it does not catch fire, because it is protected from the flame by the funnel and wire gauze.

This mode of sending up a fire-balloon is the safest, because it does not carry any fire. The late accidental and total destruction by fire of the immense fire-balloon in the grounds of the Crystal Palace sufficiently indicates the danger of these aëronautical machines, and how soon they may ignite; indeed, no Montgolfier balloon on the large scale should be used on this principle without first rendering the material of which it is composed incapable of combustion, by preparing it with a solution of phosphate of ammonia.

Robertson, in his "Recreative Memoirs," gives a very interesting account of the construction and ascent of an enormous Montgolfier or fire balloon at Vienna, in the year 1781. It was the first experiment of the kind tried there, and was carried out in a most fearless, not to say reckless, manner by Gaspard Stuver. The length of the balloon (Fig. 141), which was constructed like a cylinder closed at both ends with cones, amounted to 60 ft. It was made of



FIG. 140.—*The Paper Montgolfier.*

The sheet-iron funnel, with coarse wire gauze at the end, supported on three legs about 1 ft. from ground. An iron ladle containing tow moistened with spirits of wine, or a small fire fed with shavings, will do.

canvas lined with sized paper. Three persons ascended with Stuver in a Danube boat arranged as a car, and attached to the balloon by proper cords. They entered the car with the greater courage because they did not intend to



FIG. 141.

allow the balloon to travel where the winds might direct it, but to retain it as a "captive balloon" (like the one at the Crystal Palace) by a strong cord; but, unfortunately, the rope was not strong enough: it broke, and away went the balloon with immense rapidity, not without considerable peril to the unfortunate passengers. The shock was so violent that the boat tilted on

one side, and the fire was thrown out on the canvas. By a happy forethought, the men were provided with water and long rods to which were attached large sponges, and with these they courageously stopped the further progress of the flames. The voyage was not very long: the unwieldly machine descended a little, and knocked down a large wooden framework prepared for some pyrotechnic display: it then reascended, grazed the tops of the trees in the Prater or park, and fell on the grass on the other side of the Danube.

Amount of Expansion in Solids, Liquids, and Gases.

MEASURES OF HEAT—THERMOMETRY.

The fact that the particles or molecules of a solid body are pushed away from each other by heat, and suffer a certain increase in dimension, called expansion, has been already mentioned, and in every-day life examples are not wanting. The moulds for casting in metal are always made larger than the size required, in order to allow for the expansion of the metal when in the liquid state. The iron hoops of carriage or cart wheels are put on red hot and being cooled suddenly by the application of cold water, they contract with great force and draw all parts of the wheel firmly together. In bottles the stopper is often fixed tight, and cannot be removed by any force that is applied; when this is the case, the outer part of the neck should be carefully heated over the flame of a spirit-lamp; expansion takes place, and then the neck is tightly grasped with the hand, protected by a duster in case o

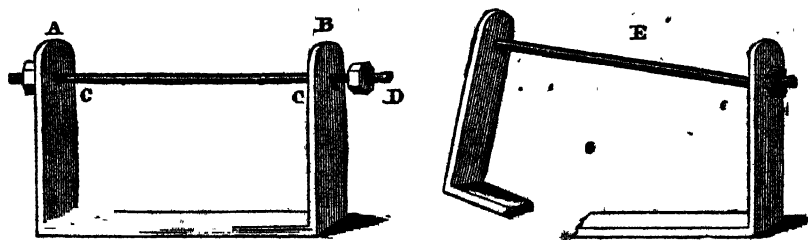


Fig. 142.

A B, cast-iron frame; C C, red-hot iron bar, passed through the holes in A B, and fitted tight by th screw D. E represents the same iron frame broken by the contraction of the bar.

accidental breakage; a slight effort, and particularly moving the stoppe backwards and forwards in one direction only, and carefully avoiding a motio which would cause the stopper to turn round, will soon be rewarded by th extrication of the stopper from the tight embrace of the neck of the bottle. A piece of iron, cast with two elbow-pieces, each bored so as to allow an iro bar to be placed through them when red hot, and then screwed up with thumb-screw as tight as possible, instantly breaks off one or both the elbow pieces when the red-hot bar is cooled by being suddenly plunged into water.

The amount of expansion, or coefficient of expansion, of solids is, howeve exceedingly small, and requires the utmost nicety of experiment to discove its amount. The difference between linear expansion, or the increase of length, and superficial expansion, or the increase in the area of a surface must of course be remembered.

The unequal expansion of metals is shown by riveting together two flat plates of iron and brass; the latter, expanding in a greater degree than the former, causes the compound bar to take the form of an arch or curve when heated; the brass side being uppermost, the arch ascends, and a convex figure is observed; but if downwards, the reverse or concave form is produced. The rise or arching of the riveted bars is easily shown if united with an electrical battery ringing a bell with which contact only is made when the curve is produced. Attention is further directed to the result of unequal expansion when the spirit-lamp is withdrawn and the bar cooled with ice or cold water; the bell ceases to ring, and the bar again becomes straight.

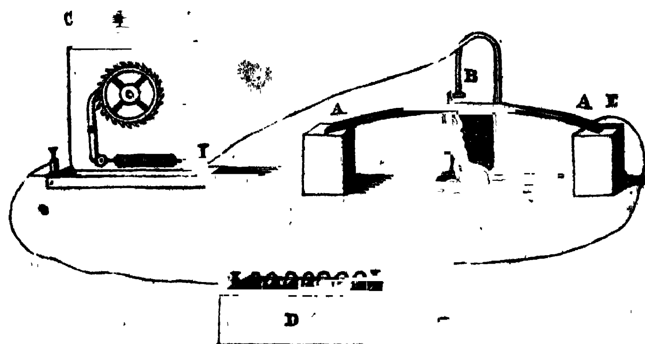


FIG. 143.

A A, The compound bar of brass and iron, heated by a spirit-lamp, and rising in a curve towards the wire B, connected with the bell C and battery D, of which the other wire is attached to the compound bar at E. When the spirit-lamp is removed, the bar contracts, and the contact is broken at B.

It is on this principle that Breguet constructs his most delicate metallic thermometers. The solid affected by heat consists of a thin metallic ribbon, composed of three strips of platinum, gold, and silver, passed through a rolling-mill together. The ribbon is then coiled in a spiral form, the platinum being outside and the silver inside; one end is fixed to a proper support, and the other is attached to a copper needle. The spiral unwinds when the heat increases, and the contrary result occurs if heat is withdrawn, and it cools. The needle moves round a scale which is graduated by direct comparison with a standard mercurial thermometer.

The following table shows the comparative increase of length or linear expansion in bars or rods of various substances when they are heated, from the freezing to the boiling point of water—viz., from 32° to 212° Fahrenheit, according to the authority of Graham:

Zinc (cast)	1 on 323	Pure gold	1 on 682
Zinc (sheet)	1 „ 340	Iron wire	1 „ 812
Lead	1 „ 351	Palladium	1 „ 1,000
Tin	1 „ 516	Glass without lead	1 „ 1,142
Silver	1 „ 524	Platinum	1 „ 1,167
Copper	1 „ 581	Flint glass	1 „ 1,248
Brass	1 „ 584	Black marble	1 „ 2,833

In this table it will be noticed that glass and platinum elongate nearly the same, and this fact explains why platinum wire can be melted into glass tubes made of glass not containing lead, such as the hard German glass, without causing the tubes to crack, either by expansion or contraction, at the points where the wires are inserted. The minute linear expansion of black marble only one on 2,833, is of course the reason why it is used as the pendulum-ro in the clock of the Royal Society of Edinburgh.

Even a bar or rod of ice elongates by an increase of temperature, and i found even to surpass zinc; the ice will elongate 1 part on 267, the zinc 1 o 323 parts. Ice will also contract when exposed to a temperature lower tha its freezing-point, and the amount of contraction has been carefully observe up to 30° or 40° below the freezing-point of water.

A solid may expand at a uniform rate up to a certain point, and then, if th heat is increased, the elongation becomes more rapid.

Amongst metals, platinum is found to expand with the greatest uniformit most probably in consequence of its great infusibility.

Certain crystals of the same nature throughout expand very unequally i their several dimensions of length, and breadth, and height, and they ar found to elongate in a greater degree in the direction of one axis than i another. Iceland spar possesses this property; and was found by Professo Mitscherlich, to expand in one direction, the crystallographic axis, and t contract in the other at right angles to the former, so that the anomaly (expansion and contraction in one body was apparent. Another remarkab anomaly of the same kind will be noticed presently in connection with a flui —viz., water—when reduced to a certain temperature. The difference betwee linear, surface, and volume expansion is determined by the geometrical pri ciple, that when a solid increases in magnitude without undergoing a chang in figure, taking the linear expansion as the unit, or say 100, the superfici expansion will be twice the linear, 100×2=200, and cubic expansion thr times the linear, 100×3=300.

Thus the linear coefficient of expansion of glass being 0·000,008, the cub expansion of the same will be 0·000,024; the dilatation of volume and surfa of solids being calculated from linear expansion.

THE EXPANSION OF LIQUIDS.

It has already been noticed that the expansion of solids by heat is so co trolled by the antagonistic force of cohesion, that it is not perceptible to t vision without the use of secondary means, such as those described at page 12

With liquids the amount of expansion is very perceptible when they a inclosed in narrow glass tubes, and in fact is much greater than that of soli because the force of cohesion is diminished so much that every particle free to move upon its neighbouring particles. Some fluids expand more th others. Alcohol is more expansible than water, and water more than mercur in fact, alcohol expands six times more than mercury. Messrs. Dulo and Petit employed the most refined means to ascertain the rate of, a absolute expansion of, mercury, and they found that the coefficient of t latter was 1-5550 between the freezing and boiling point of water, the ra being as follows:

From	0° to 100° Centigrade,	mercury	expands	1	measure, or	$55\frac{1}{2}$
,,	100° to 200°	,,	,,	1	,,	$54\frac{1}{3}$
,,	200° to 300°	,,	,,	1	,,	53

Liquid carbonic acid expands four times more than air, and, when heated from 32° to 86 Fahrenheit, 100 measures expand to 140.

There are other fluids, such as liquid sulphurous acid, hyponitrous acid, cyanogen, and the chloride of ethyle, which also expand very considerably when heated.

Alcohol and bisulphide of carbon expand uniformly, which is another curious fact, because their boiling-points are so different, the former—alcohol—being 173°, the latter 116°.

Liquids, as a rule, expand by heat, and contract by cold.

There is, however, a remarkable exception, probably more apparent than real when the theory of the expansion of liquid is better understood, that water which becomes solid in all parts of the globe at the level of the sea at 32 Fahrenheit, or of 0° Centigrade, expands instead of contracting when the water reaches a temperature of 40° Fahrenheit, and falls to 32°: the amount of expansion is not very great, being one part in ten thousand at 32°.

But the fact, which at first was thought illusory, is indisputable, as proved by the experiments of Dr. Hope. He placed two thermometers in a large vessel of water, the one being at the top, and the other at the bottom. Up to a temperature of 40°, the cold water contracted, and, being the heavier, sank to the bottom, and the lower thermometer registered the greatest cold. After 40° was passed, the water evidently expanded; the coldest water was found to be at the top, and duly recorded by the thermometer sinking to 32°, whilst the warmer water, which ought, according to the law of expansion, to have been uppermost, remains at the bottom, and therefore was heavier, bulk for bulk, than the water about to crystallize. It is this remarkable exception that preserves the fish in the lakes and rivers. During the severe winters of Siberia the water is frozen many feet thick; but it is related by one of the exiles in this roomy but severe prison, that part of their amusement in certain seasons consisted in fishing in great holes in the ice, and all they caught they partially but immediately ate raw and living, biting out a piece of the back, which was declared to be a most agreeable tit-bit.

FIG. 144.
Dr. Hope's experiment.

It is evident that the fish, if frozen, could have no power of locomotion—they must die; so that on the arrival of winter the Siberian waters would throw up their dead fish, as all would be killed if the water, which is a very bad conductor of heat, did not remain at 40° at the bottom of the lakes, rivers, and seas.

Bismuth is said to possess the same curious property of expanding whilst it is being cooled, and thus iron bottles filled with melted bismuth, and plugged with a screw, burst at the moment the metal assumes the solid state. A bomb-shell or cast-iron bottle filled with water, and screwed up, bursts in the

same manner if surrounded with a freezing mixture of pounded ice, or snow and salt. With respect to bismuth it is right to state that Professor Tyndall's conclusion on this similarity, stated in his work on "Heat as a Mode of Motion," in which it is asserted "that the anomalous expansion of water in the act of cooling below 40° Fahrenheit is by no means an isolated instance of the kind, but that other bodies, and particularly melted bismuth, participates in this extraordinary property of expanding near the point of solidification," is opposed by Mr. Alfred Tribe, who, after making experiments upon this

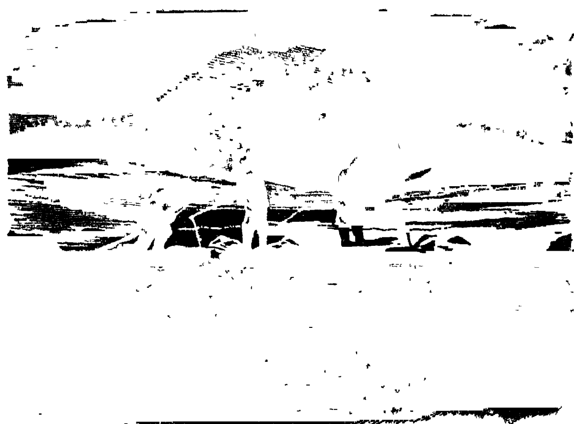


FIG. 145.—*Siberian Exiles fishing.*

subject, considers that the analogy between water and bismuth is imperfect, since in the case of the molten metal there is no perceptible range of temperature through which it expands on cooling. The act of solidification is itself accompanied by an increase in bulk; but there is no evidence of this expansion taking place prior to the act of crystallization. When the crystallization of any salt is exhibited on the disc with the oxy-hydrogen microscope, the visible illustration of the motion of the particles is very decided, as the crystals shoot out and interlace with each other. The act of solidification is, therefore, one of motion, and heat is produced, and very decidedly so in the case of sulphate of soda or glauber salt. A large flask filled with a saturated solution of sulphate of soda, and carefully closed with a cork and bladder, so that the air is excluded, does not solidify when cold. Crystallization only begins when the air is admitted; the solution of a minute volume of air liberates a tiny crystal, and, the nucleus once formed, cohesion sets in with rapidity; the molecules are set in motion, and sufficient heat is produced to be felt by the hand, and becomes still more apparent if a delicate air-thermometer is used. India-rubber caoutchouc, when stretched and apparently expanded, becomes warm instead of cold; is it possible to suppose that the expansion in the direction of the length may cause contraction in the transverse direction in the breadth, and the sum of this violent motion is in favour of the contraction, and thus heat is the result?

The contraction of stretched or expanded caoutchouc by heat is another

remarkable anomaly. It was suggested by Mr. Thompson that it might shorten if heated, and the fact was proved by Tyndall, who first stretched a vulcanized india-rubber tube by a ten-pound weight, and surrounding it with hot air, the caoutchouc tube contracted and lifted the weight. In this case, motion, the stretching of the caoutchouc, eliminates heat, which again produces motion when the stretched caoutchouc is warmed and lifts the weight by the contraction of its substance.

The expansion of fluids by heat, and the reverse, is taken advantage of in the construction of those useful instruments called thermometers, or heat-measurers.

A glass tube with a small bore, sufficiently so to be capillary, is selected with care, in order to secure the same diameter throughout. The bores of some tubes are like an elongated cone, and, if they were used, the mercury would expand much more in some parts of the tube than in others, and hence the indications of such a thermometer would be incorrect. A little mercury, amounting to an inch in length, is allowed to enter the tube, and being moved from one end of the tube to the other, it is soon discovered whether the mercury increases or decreases in length, or remains, as is usually the case, of the same linear dimensions in all parts. The proper length having been cut off, one end is melted and blown out into a bulb, the other being formed into a cup or funnel-shape form, to hold the mercury, which is forced in; the tube is now inclined slightly, and the air in the bulb expanded by heat; it is afterwards allowed to cool, and, as the air cools and contracts, the mercury from the upper funnel is forced in by the pressure of the air, and enters to supply the place of the air driven out by expansion. To get rid of the rest of the air, the mercury is alternately boiled and cooled until the bulb and part of the tube are full of mercury.

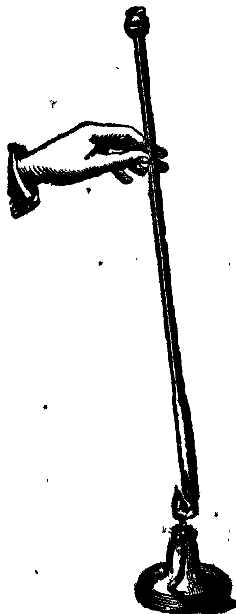


FIG. 146.

Having thus filled the bulb and one-third of the tube, the next step is to seal it hermetically, which is done by heating the mercury to the boiling-point, and at the moment the mercury is overflowing at the summit the glass is fused with a flame, urged by a blow-pipe (Fig. 147), before the mercury has had time to contract; and if this operation has been skilfully performed, a perfectly void space, or vacuum, free from air, is obtained as the mercury sinks or contracts in the bulb and tube.

The instrument in its present state will show an increase or decrease of heat by the rising or falling of the mercury; but such indications would be useless, and it would be impossible to compare the observations made by any two ungraduated bulbs or tubes filled with mercury in the manner already described.

The graduation of the instrument is, therefore, of paramount importance, and standard-points must be obtained—such, that they shall be the same in every thermometer, whatever may be the scale.

Sir Isaac Newton enjoys the merit of having selected the temperature of

ice, which is dissolving and liquifying, for one point, and boiling water, emitting steam freely and without pressure, for the other. Ice always *melts* at the same temperature, and pure water invariably *boils* at the same temperature, when the barometer stands at 29 8 in.

It is only necessary to immerse the thermometer alternately in melting ice and in boiling water, with certain precautions, and to mark the point at which the mercurial column stands—one being called the freezing-point, and the other the boiling-point.

The instrument must be immersed in the melting ice until the mercury becomes perfectly stationary. The immersion in boiling water requires the greatest care, and a time should be selected when the barometer stands at 29·8 or 30 in. The depth of the water in the vessel should not exceed 2 in.



FIG. 147.—*Blow-pipe work in Negretti and Zambra's Thermometer Room.*

The vessel must not be a shallow one, but sufficiently deep to contain the bulb and nearly all that part of the tube up which the mercury will rise when placed in boiling water. Distilled water should be used, and brisk ebullition maintained, and the steam allowed to escape freely, as any confinement of it would raise the temperature above that of boiling water. The space or interval between the two points is now divided into any number of equal parts, which vary according to the scale used (Fig. 148.)

In England, the interval according to Fahrenheit is divided into 180 parts, the zero being 32° below the freezing-point. On the Continent, the interval is divided by Celsius into 100 parts, and is called the Centigrade scale,—the zero commences with the freezing-point; sometimes into 80 parts, called Réaumer's scale, the zero, as before, being the freezing-point of water. Of the three, that of Celsius is the most simple, and will be gradually adopted throughout the civilized world.

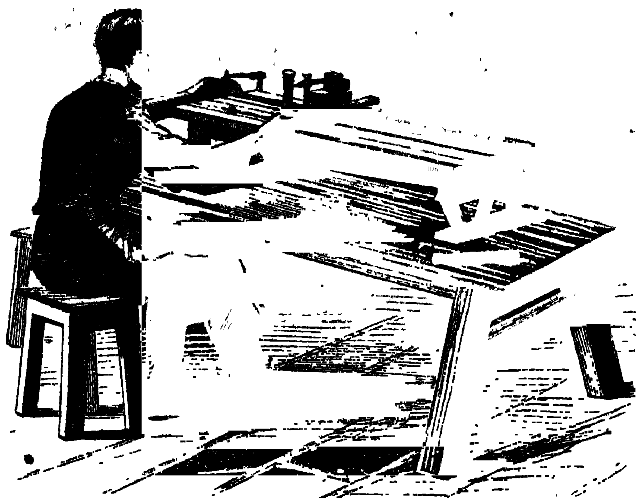


FIG. 148.—*Graduation, by a Machine, of the Tubes after the freezing and boiling points have been determined.*

These scales are easily reduced from one to another by ascertaining their numerical relation.

Thus 180 is to 100 as 9 to 5;
180 „ 80 „ 9 „ 4.

Fahrenheit's is, therefore, reduced to the Centigrade scale by multiplying by 5 and dividing by 9; or to that of Réaumer by multiplying by 4 and dividing by 9.

The Celsius or Centigrade and Réaumer's scales are reduced to Fahrenheit's scale by reversing the process: the multiplier in both cases being 9, the divisor will be 5 with Centigrade and 4 with Réaumer.

The reduction is, however, a little complicated when it is remembered that Fahrenheit's zero is 32° *below* the freezing-point of water, so that in all these calculations 32 must be first subtracted when Fahrenheit is reduced to Centigrade or Réaumer, and added when the contrary is required.

1st Example. To reduce 212° Fahrenheit to Centigrade: 212°—32°=180°× 5=900÷9=100° C.

2nd Example. To reduce 100° Centigrade to Fahrenheit: 100°×9=900÷5=180°+32°=212° F.

The freezing-point of water is therefore designated and known in all books by the following expressions: 0° C., 0° R., 32° F.

The boiling-point of water, by 100° C., 80° R., 112° F.; C. being Centigrade, R. Réaumer, and F. Fahrenheit.

The limits to the use of the mercurial thermometer are the points at which the metal solidifies, or is frozen, viz., at 39° below zero F., or at which the metal boils, 662° F., or 450° above the boiling-point of water; hence in the one case degrees of extreme cold are registered by thermometers filled with

alcohol, which has never been known to freeze at the greatest known cold; and, in the other case, all temperatures above 662° may be registered, to a certain point, by the air-thermometer; but all temperatures which soften glass and go beyond that point can be estimated only by the pyrometer. The air-thermometer will be explained in treating of the expansion of gases; and in ending the description of the ordinary mercurial thermometer, it may be stated that the bulbs are liable to a permanent change of capacity, which displaces the zero; hence it is usual to keep standard thermometers three or four years before they are graduated.

Thermometers are constructed for a variety of purposes, and have, therefore, different names given to them. In illustration of this statement, we give a drawing of Negretti and Zambra's maximum thermometer for registering the highest daily temperature of the air, or degree of heat at any particular hour of the day—

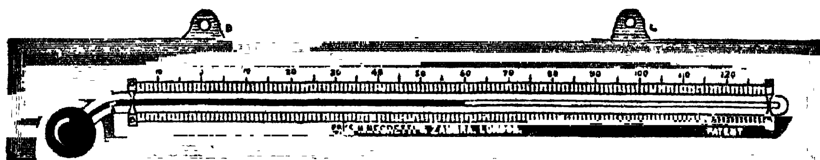


FIG. 149.—*The Maximum Thermometer,*

the construction of which is as follows:—A small piece of glass is inserted in the bend near the bulb, and within the tube, which it nearly fills: at an increase of temperature, the mercury passes this piece of glass; but on a decrease of heat, not being able to recede, it remains in the tube, and thus indicates the maximum temperature. After reading, it is easily adjusted. Hitherto every series of meteorological observations has been more or less broken by the frequent plunging of the steel index into the mercury, or becoming otherwise deranged. Messrs. Negretti and Zambra have, in their maximum thermometer, supplied a want long felt.

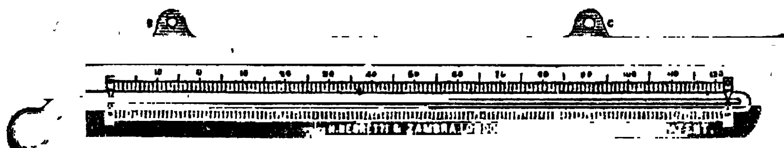


FIG. 150.—*The Alcohol or Minimum Thermometer*

consists of a glass tube, the bulb and part of the bore of which is filled with perfectly pure spirits of wine, in which floats freely a black glass index. A slight elevation of the thermometer, bulb uppermost, will cause the glass index to flow to the surface of the liquid, where it will remain, unless violently shaken. On a *decrease* of temperature, the alcohol recedes, taking with it the glass index; on an *increase* of temperature, the alcohol alone ascends in the tube, leaving the end of the index *furthest* from the bulb indicating the minimum temperature.

Directions for using the Minimum Thermometer for determination of the Minimum Temperature of the Air.—Having caused the glass index to flow to the end of the column of spirits, by slightly tilting the thermometer bulb uppermost, suspend the instrument in the shade, with the air passing freely to it on all sides, by the two brass plates attached for that purpose, in such manner that the bulb is about half an inch lower than the upper, or the end of the thermometer furthest from the bulb,—then, on a decrease of temperature, the spirits of wine will descend, carrying with it the glass index; on an increase of temperature, however, the spirits of wine will ascend in the tube, leaving that end of the small glass index furthest from the bulb indicating the minimum temperature. To re-set the instrument, simply raise the bulb end of the thermometer a little, as before observed, and the index will again descend to the end of the column, ready for future observation. The same instrument may be used as a terrestrial radiation thermometer, and when in use is to be placed with its bulb fully exposed to the sky, resting on grass, with its stem supported by little forks of wood.

By no means jerk or shake an alcohol minimum thermometer *when re-setting* it, for by so doing it is liable to disarrange the instrument, either by causing the index to leave the spirit, or by separating a portion of the spirit from the main column.

As alcohol thermometers have a tendency to read lower by age, owing to the volatile nature of the alcohol allowing particles in the form of vapour to rise and lodge in the tube, it becomes necessary to compare them occasionally with a mercurial thermometer whose index error is known; and if the difference be more than a few tenths of a degree, examine well the upper part of the tube to see if any alcohol is hanging in the bore thereof; if so, the detached portion of it can be joined to the main column by swinging the thermometer with a pendulous motion, *bulb downwards.*

THE PYROMETER.

One of the most celebrated contrivances for estimating high temperatures was that of Mr. Wedgwood; but, as the indications depended on the contraction of clay cylinders, which will contract as much by the long continuance of a comparatively low heat as by a short continuance of a high one, they were enormously exaggerated, and could not be correct. The late Professor Daniell improved greatly upon Wedgwood's instrument, and, by using the linear expansion of bars of metal, arrived much nearer to a correct estimate of temperatures above a dull red heat. Daniell calls his instrument the register pyrometer, and describes it as follows: "It consists of two parts, which may be distinguished as the register and the scale. The register is a solid bar of blacklead earthenware, highly baked. In this a hole is drilled, into which a bar of any metal, six inches long, may be dropped, and which will then rest upon its solid end. A cylindrical piece of porcelain, called the index, is then placed upon the top of the bar, and confined in its place by a ring or strap of platinum passing round the top of the register, which is partly cut away at the top, and tightened by a wedge of porcelain. When such an arrangement is exposed to a high temperature, it is obvious that the expansion of the metallic bar will force the index forward to the amount of the excess of its expansion over that of the blacklead, and that, when cooled, it will be left at the point of greatest elongation. What is now required is the measurement of the

distance which the index has been thrust forward from its first position; and this, though in any case but small, may be effected with great precision by means of the scale.

"This is independent of the register, and consists of two rules of brass accurately joined together at a right angle by their edges, and fitting square upon two sides of the blacklead bar. At one end of this double rule a small plate of brass projects at a right angle, which may be brought down upon the shoulder of the register, formed by a notch cut away for the reception of the index.

"A movable arm is attached upon this frame, turning upon its fixed extremity upon a centre, and at its other carrying an arc of a circle, whose radius is

FIGS. 151, 152.

exactly 5 in., accurately divided into degrees and thirds of a degree. Upon this arm at the centre of the circle another lighter arm is made to turn, one end of which carries a nonius with it, which moves upon the face of the arc, and subdivides the former graduation into minutes of a degree; the other end crosses the centre, and terminates in an obtuse steel point, turned inwards at a right angle.

"When an observation is to be made, a bar of platinum or malleable iron is placed in the cavity of the register; the index is to be pressed down upon it, and firmly fixed in its place by the platinum strap and porcelain wedge. The scale is then to be applied by carefully adjusting the brass rule to the sides of the register, and fixing it by pressing the cross piece upon the shoulder, and placing the movable arm so that the steel point of the radius may drop into a small cavity made for its reception, and coinciding with the axis of the metallic bar.

"The minutes of the degree must then be noted, which the nonius indicates upon the arc. A similar observation must be made after the register has been

exposed to the increased temperature which it is designed to measure, and again cooled, and it will be found that the nonius has been moved forward a certain number of degrees or minutes, as shown at Figs. 151 and 152."

Fig. 151 represents the register; A is the bar of black lead; *a* the cavity for the reception of the metallic bar; *c c'* is the index, or cylindrical piece of porcelain; *d*, the platinum band, with its wedge, *e*.

Fig. 152 is the scale by which the expansion is measured: *f* is the greater rule, upon which the smaller, *g*, is fixed square. The projecting arc *h* is also fitted square to the ledge under the platinum band *d*.

D is the arm which carries the graduated arc of the circle E, fixed to the rule *f*, and movable upon the centre *i*.

C is the lighter bar fixed to the first, and moving upon the centre *k*.

H is the nonius at one of its extremities, and *m* the steel point at the other.

The rule *g* admits of adjustment on *f*, so that the arm *h* may be adjusted to the centre *i*, in order that at the commencement of an experiment the nonius may rest at the beginning of the scale.

The term "nonius," used by Daniell, is only another name for vernier, a contrivance for measuring intervals between the divisions of graduated scales on circular instruments.

The scale of this pyrometer is readily connected with that of the thermometer by immersing the register in boiling mercury, whose temperature is as constant as that of boiling water, and has been accurately determined by the thermometer.

The amount of expansion for a known number of degrees is thus determined, and the volume of all other expansions may be considered as proportional.

The melting-point of cast iron has been thus ascertained to be 2786°, and the highest temperature of a good wind-furnace about 3300°—points which were estimated by Mr. Wedgwood at 20,577° and 32,277° respectively.

Mr. Wedgwood, indeed, makes an observation which is calculated to throw suspicion upon the accuracy of his results; for he says, "We see at once how small a portion (of the rays of heat) is concerned in animal and vegetable life, and in the ordinary operations of nature. From freezing to vital heat is barely 1-500th part of the scale—a quantity so inconsiderable relatively to the whole that in the higher stages of ignition ten times as much might be added or taken away without the least difference being discoverable in any of the appearances from which the intensity of fire has hitherto been judged of."

Now this, remarks Daniell, "is utterly unlike the gradual progression by which the operations of nature are generally carried on; and the fact is, that a regular transition may be traced from one remarkable point of temperature to another."

Thus from the freezing of water, 32°, to vital heat in man is 60°.

$60 \times 3 = 180°$	Boiling water.
$60 \times 7 = 420°$	Melted tin.
$60 \times 10 = 600°$	Boiling mercury.
$60 \times 15 = 900°$	Red heat.
$60 \times 31 = 1860°$	Melting silver.
$60 \times 45 = 2700°$	Melting cast iron.
$60 \times 55 = 3300°$	Highest heat of wind-furnace.

Before the invention of the register pyrometer, the expansion of solids had never been ascertained beyond the temperature of 527°: the following

table exhibits the progressive amount of several metals to their point of fusion, as determined by Daniell's pyrometer:

PROGRESSIVE DILATATION OF SOLIDS.

One millon parts at 62°.

	At 212°.	At 662°.	At Fusing-point.
Blacklead ware .	1,000,244	1,000,703	
Wedgwood ware .	1,000,735	1,002,995	
Platinum . .	1,000,735	1,002,995	1,009,926 (maximum, but not fused).
Iron, wrought .	1,000,984	1,004,483	1,018,378 to the fusing-point of cast iron.
Iron, cast . .	1,000,893	1,003,943	1,016,389
Gold . . .	1,001,025	1,004,238	
Copper . .	1,001,430	1,006,347	1,024,976
Silver . . .	1,001,626	1,006,886	1,020,640
Zinc . . .	1,002,480	1,008,527	1,012,621
Lead . . .	1,002,323	...	1,009,072
Tin . . .	1,001,472	...	1,003,798

Professor Daniell concludes his dissertation by the following passage, which is quite in accordance with those notions which Tyndall has so ably contended for—viz., that heat is a mode of motion:—"The amount of the force which produces these expansions and contractions, measured by any opposing force, that of cohesion, for instance, is enormous.

"Some idea may be formed of it, when it is understood that it is equal to the mechanical force which would be necessary to produce similar effects in stretching or compressing the solids in which they take place. Thus, a bar of iron heated so as to increase its length a quarter of an inch, by this slow and quiet process exerts a power against any obstacle by which it may be attempted to confine it, equal to that which would be required to reduce its length by compression to an equal amount. On withdrawing the heat, it would exert an equal power in returning to its former dimensions."

M. Molard used this great moving force to restore the walls of a building to the perpendicular which had been bulged, and the same principle was used at the Cathedral of Armagh.

THE EXPANSION OF GASES.

We now come to the most expansible bodies—viz., the gases; and, although at first there was considerable doubt whether they all expanded alike, because the experimentalists had neglected to remove the moisture—the aqueous vapour—from them, it was finally discovered, not only by Gay-Lussac in Paris, but by our own countryman, the illustrious Dr. Dalton, that all gases expand alike with the same amount of heat, and that the rate of dilatation continues uniform for all temperatures. In discovering the expansibility

of liquids it was found that cohesion was not quite overcome, and that there was still a considerable amount of that force which tended to keep the particles in contact. This, however, is not the case with gases; the cohesive power is for the time completely overcome by the motion of heat. Sir H. Davy speaks emphatically upon this motion in his "Chemical Philosophy." "It seems possible to account for all the phenomena of heat, if it be supposed that in solids the particles are in a constant state of vibratory motion, the particles of the hottest bodies moving with the greatest velocity and through the greatest space; that in fluids and elastic fluids, besides the vibratory motion, which must be conceived greatest in the last, the particles have a motion round their own axes with different velocity, the particles of elastic fluids (gases) moving with the greatest quickness; and that in ethereal substances the particles move round their own axes, and separate from each other, penetrating in right lines through space. Temperature may be conceived to depend upon the velocity of the vibration, increase of capacity in the motion being performed in greater space; and the diminution of temperature during the conversion of solids into fluids or gases may be explained on the idea of the loss of vibratory motion in consequence of the revolution of particles round their axes at the moment when the body becomes fluid or aëriform, or from the loss of rapidity of vibration in consequence of the motion of the particles through space."

It has been proved that gases expand by 1-490th of their own volume for every degree of Fahrenheit's scale between the freezing-point, 32°, and the boiling-point of water, 212°, and so on at higher or lower temperature, provided the pressure of the air remains the same. If the Centigrade scale is used, the ratio of expansion of any gas will be 1-273rd of its volume for every degree.

490	cubic inches	of air	at 32°	become	491	at	33°
491	"	"	33	"	492	"	34
492	"	"	34	"	493	"	35

From a most careful series of experiments it has been determined that "the coefficient of expansion" of all gases, expressed in decimals, is 0·00,366. These figures are near enough for all ordinary calculations; although it must be observed that, speaking rigidly, this is not exactly the case, except probably with the three permanent gases, oxygen, hydrogen, and nitrogen,—in all the other gases and vapours the expansion being greatest for those which are most readily condensible.

M. Regnault has made the most elaborate and careful experiments, and determined that one thousand volumes of certain gases at 0° C. or 32° F. (the pressure of the air remaining unchanged) become expanded in the following proportions when heated to 100° C., or 212° F.:

Air	1,367·06	Hydrogen	1,366·13
Carbonic acid	1,370·99	Hydrochlorine acid	1,368·12
Carbonic oxide	1,366·88	Nitrogen	1,366·82
Cyanogen	1,387·67	Nitric oxide	1,371·95

It will be apparent that hydrogen expands the least, and, as might be expected, cyanogen, which is liquified with comparative ease, is much higher —viz., 1,387·67. It is, therefore, apparent that if the coefficient of expansion remains the same with all gases, that cyanogen should have been represented

by the same figures as those which belong to air—instead of being 0·00,387 to 0·00,367 atmospheric air. The conversion of this property of expansion into power or motion is well described by Tyndall :—"Suppose I have a quantity of air contained in a very tall cylinder (A B, Fig. 153), the transverse section of which is one square inch in area. Let the top, A, of the cylinder be open to the air, and let P be a piston, which, for reasons to be explained immediately, I will suppose to weigh two pounds one ounce, and which moves air-tight and without friction up or down in the cylinder. At the commencement of the experiment let the piston be at the point P of the cylinder, and let the height of the cylinder from its bottom B to the point P be 273 inches, the air underneath the piston being at a temperature of 0° C. Then, on heating the air from 0° to 1° C., the piston will rise one inch; it will now stand at 274 inches above the bottom. If the temperature be raised two degrees, the piston will stand at 275 ; if raised three degrees, it will stand at 276; if raised ten degrees, it will stand at 283; if 100 degrees, it will stand at 373 inches above the bottom; finally, if the temperature were raised to 273° C., it is quite manifest that 273 inches would be added to the height of the column; or, in other words, that by heating the air to 273° C. *its volume would be doubled*. The gas in this experiment executes work. In expanding from P upwards, it has to overcome the downward pressure of the atmosphere, which amounts to 15 lbs. on every square inch, and also the weight of the piston itself, which is 2 lbs. 1 oz. Hence, the section of the cylinder being one square inch in area, in expanding from P to P′ the work done by the gas is equivalent to the raising a weight of 17 lbs. 1 oz., or 273 ounces, to a height of 273 inches. It is just the same as what it would accomplish if the air above P were entirely abolished, and a piston weighing 17 lbs. 1 oz. were placed at P.



FIG. 153.

"Let us now alter our mode of experiment, and, instead of allowing our gas to expand when heated, let us oppose its expansion by augmenting the pressure upon it; in other words, let us keep *its volume constant* while it is being heated.

"Suppose, as before, the initial temperature of the gas to be 0° C., the pressure upon it, including the weight of the piston P, being as formerly 273 ounces. Let us warm the gas from 0° C. to 1° C.; what weight must we add at P in order to keep its volume constant? Exactly one ounce.

"But we have supposed the gas at the commencement to be under a pressure of 273 ounces, and the pressure it sustains is the measure of its elastic force; hence, by being heated 1°, the elastic force of the gas has augmented by 1-273rd of what it possessed at 0°. If we warm it 2°, two ounces must be added to keep its volume constant; if 3°, three ounces must be added; and if we raise its temperature 273°, we should have to add 273 ounces, that is, we should have to *double the original pressure* to keep its volume constant.

"In the first case marked out, it is shown that by heating the air to 273° C. its volume would be doubled. In the second, that by compressing the air with 273 ounces we may heat it to 273° C., and have, consequently, double the

original pressure to keep the air confined to the same volume. In fact, the volume being kept constant, the elastic force is doubled.

"But are the *absolute quantities* of heat imparted in both cases the same? By no means. Supposing that to raise the temperature of the gas, whose volume is kept constant, 273°, ten grains of combustible matter are necessary; then to raise the temperature of the gas, whose *pressure* is kept constant, an equal number of degrees would require the combustion of 14¼ grains of the same combustible matter. *The heat produced by the combustion of the additional 4¼ grains in the latter case is entirely consumed in lifting the weight.* Using the accurate numbers, the quantity of heat applied when the volume is constant is, to the quantity applied when the pressure is constant, in the proportion of 1 to 1·421.

"This extremely important fact constituted the basis from which the mechanical equivalent of heat was first calculated."

Various methods have been contrived to determine the amount of expansion of gases when subjected to a uniform pressure, and one of the most simple is that of Monsieur Pouillet (Fig. 154), described by Lardner.

"An iron syphon tube, D C, is formed with short legs, from the bottom of which proceeds a pipe with a stop-cock F, under which is placed a cistern or reservoir G. In the legs of the syphon D C are inserted two glass tubes, D E and C B, of more than thirty inches in height. The tube D E is open at the top; the tube C D is closed at the top, but has a horizontal branch united to it, at B, which is connected with a tube, A B, made of platinum, which terminates in a hollow globe or ball, A, also made of platinum. In the tube B A is fixed a stop-cock in order to communicate at pleasure with the atmospheric air.

"The stop-cock F being closed, and the stop-cock in the tube B A being open, mercury is poured into the tube D E, so as to fill the glass tubes D E and C B nearly to the top. Since the tubes D E and C B both communicate with the external air, the columns of mercury in them will stand at the same level.

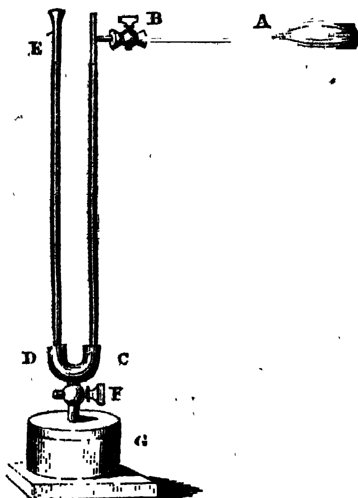


FIG. 154.—*Pouillet's Apparatus.*

"To determine the expansion which air suffers when raised from the freezing-point to the boiling-point under uniform pressure, let the ball A be immersed in a bath of melting ice, so as to reduce the air included in it to the freezing-point. Let the stop-cock in the tube B A be then closed, and let the bulb A be removed to a bath of boiling water. The air in the bulb, expanding, will press down the column of mercury in B C, and will cause the column in D E to rise; so that the levels of the two columns will no longer coincide. But they may be equalized by opening the stop-cock F, and allowing mercury to flow into the reservoir G from the syphon until the levels in the two legs come to the same point. When that is accomplished, the pressure upon the expanded

air included in the bulb A and the tube communicating with it will be equal to that of the atmosphere, and equal to that which the same air has when at the freezing-point.

"The capacity of the tube C B being known, the volume which corresponds to any length of it will be also known; also the increment of volume which the air has suffered by expansion will be indicated by the height through which the mercury has fallen in the tube C D. This increment, therefore, will be the dilatation of the air included in the bulb A and the communicating tube between the freezing and the boiling points. In the same manner, by this apparatus, the dilatation corresponding to any change whatever of temperature under a given pressure can be ascertained."

The expansion of air by heat, and the uniformity with which it takes place, suggested at a very early period of science the use of air-thermometers, which are the most delicate and, with certain precautions, the most reliable in certain cases where high temperatures have to be determined. The first is supposed to have been constructed by a learned Italian physician, named Sanctorius, about the year 1590. It is sometimes attributed to Cornelius Drebel, who introduced it in the year 1610; but this is a mistake. Drebel followed Sanctorius, and therefore cannot be the first inventor, although there is every reason to suppose that he made his air-thermometer in perfect ignorance of what Sanctorius had already done.

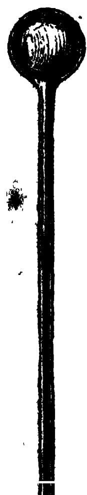


FIG. 155.
The Air-Thermometer of Sanctorius.

The construction is very simple: it consists of a glass tube at the end of which a bulb or ball is blown; this tube, with its ball, is then fitted into some convenient glass vessel or bottle, containing a little coloured water. On the application of heat, either from the palm of the hand or the flame of a spirit-lamp, a portion of the air in the tube is expelled, and, when cold, the water ascends to fill its place; the rise or fall of this column of coloured water by the expansion or contraction of the air in the bulb is supposed to indicate the difference of temperature.

It was soon discovered that this air-thermometer was not correct in its indications, and was, in fact, affected by the pressure of air: when the barometer fell, the air expanded in the bulb, and the coloured fluid was driven downwards; or, on the contrary, if the barometer rose, the air, contracted by the increased pressure on the liquid, was pushed higher up the tube. Sir John Leslie greatly improved upon the rude apparatus already described, and invented a very elegant instrument, called the *Differential Air Thermometer* (Fig. 156), which has been of the greatest use in the refined experimental researches made for the elucidation of the more obscure properties of the force called heat.

It consists of two glass bulbs or balls connected together by a tube bent twice at right angels. The balls contain air, and, just before they are hermetically closed, a little sulphuric acid, coloured with carmine, is introduced, so that it rises to about half the height of the two tubes bent at right angles.

The ball left open for the introduction of the coloured fluid is now finally closed, and as both bulbs must be equally affected by changes of temperature in the surrounding air, the liquids in the tubes remain in equilibrium.

If, however, one of the balls is grasped by the hand, the air expands, and the fluid is driven up the other tube, which is provided with a proper scale; thus at any moment, by placing one ball in a particular spot where heat is to be discovered, the expansion of the air becomes a most sensitive and delicate means of appreciating any small amount of heat.

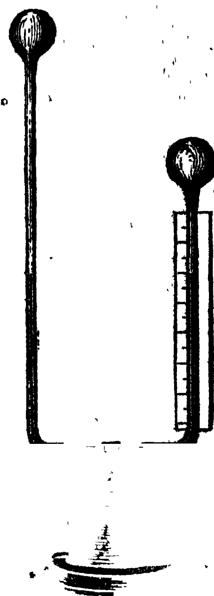


FIG. 156.- *Leslie's Differential Thermometer.*

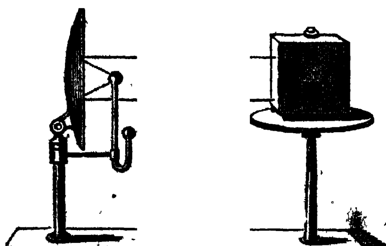
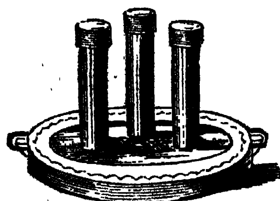


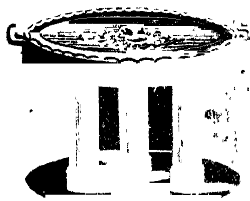
FIG. 157.—*Differential Thermometer used to discover Focus of Heat Rays.*

CONDUCTION.

Our ideas of this property of heat, of travelling along and through material substances, are quickly formed and put in practice. If a bar of iron and a rod of glass are thrust between the bars of a grate containing burning fuel, we soon learn which we may first touch or take out with impunity. The iron rapidly becomes so hot throughout its length and breadth, that we cannot lay hold of it; the glass rod may be quite softened within a few inches of the hand, and yet the heat is not sensibly felt or becomes so great as to prevent the rod of glass being held in the hand: in the one case there appear to be regular stepping-stones across which the heat may, as it were, take its way; in the other there is no regular path provided, and the travelling power of the heat is interfered with, and so greatly impeded that a considerable time must elapse before any sensible progress or travelling of the heat can be recorded. Thus in early days the wise men of the period rudely divided all substances into conductors and non-conductors of heat. Such a division, however, is not in accordance with nature; there are intermediate conditions of conductivity, and thus we come to speak of good and bad conductors of heat.

*In regarding heat by the dynamical theory, the student can have no difficulty in understanding that the position of the solid substance under examination in the list of good or bad conductors must depend greatly upon its physical structure. The metals are good conductors; there is uniformity of internal structure, and the vibratory movement necessary to set the heat-waves in motion is regular and not interfered with; moreover, the particles are in close contact. Glass is a bad conductor, because those conditions which are necessary for the setting up of molecular motion are not fulfilled; the vibrations are not communicated steadily from molecule to molecule, but broken up and thrown into confusion; the glass has no regular molecular homogeneity—it is too heterogeneous. Any substance which can transmit molecular motion is a good conductor of heat, and those bodies which do not transmit this motion readily are bad conductors.





FIGS. 158 and 159.—*Griffiths' experiment.*

The difference between the conducting power of a metal, an earth, and an earthy compound may be illustrated by the following simple and instructive experiment: *

Provide solid cylinders of these three materials, viz., iron, sandstone, and chalk; let these be 1 in. in diameter and 6 in. long, and perfectly flat at each of their ends.

Place a cup, containing an ounce of tallow, upon the warm hob of the grate; and when the tallow is perfectly melted, dip into it for about half an inch one end of the iron cylinder, and then lift it out; a portion of tallow will adhere, and quickly become solid, because the iron, by good conducting power, deprives it of the heat of fluidity.

Dip one end of each of the other cylinders in the same way; they will attract or absorb a considerable portion of the melted tallow, and some time will be required before it will become equally solid with that on the iron cylinder, because sandstone and chalk have not sufficient conducting power to deprive it of heat in a similar degree.

Dip the end of all three cylinders again, and lift them out, and, when the tallow becomes solid, dip them again, and lift them out until they have all obtained an equal coating of tallow; then allow them to cool. Pour boiling water into a "hot-water plate," and place the three cylinders to stand upon it at equal distances, with their coated ends uppermost, as shown in Fig. 158.

* "Chemistry of the Four Seasons," Griffiths.

In the course of a few minutes, the iron will again prove its good conducting power by melting the tallow; but the sandstone and chalk will prove their bad conducting power by the tallow remaining solid during the whole time that the water is cooling down to common temperature.

By reversing the arrangement of the last experiment, namely, by applying heat above, instead of beneath, the cylinders, it can be proved that neither the conducting power of the iron nor the non-conducting power of the sandstone and chalk are in the least degree affected or modified.

Let the iron cylinder be again coated with tallow, but pare away all from its circular extremity, that it may now stand firmly upon this, and have only a ring of tallow, about half an inch wide, around its circumference; do the same with the cylinders of sandstone and chalk; then set the three at equal distances within a circle similar in diameter to the bottom of the hot-water plate, that they may form a tripod for its support (this arrangement must be made upon a steady table); then remove the plate, without disturbing the cylinder, fill it with boiling water, and carefully replace it to stand upon them, as represented in Fig. 159.

The three cylinders will now be subjected to heat applied from above, instead of from below, as in the last experiment (Fig. 158); but this arrangement will cause no difference in their conducting power, or non-conducting power, as will be proved in the course of a few minutes by the ring of tallow melting from the iron cylinder, whilst that upon each of the other cylinders remains solid as before.

Starting with gold, and taking it as the type of a good conductor, and giving it the first place in a scale amounting to 100, we have the following tabulated results obtained by Franklin and Igenhausz, by watching the rate at which wax was melted at the end of bars of

Gold	100·00	Tin	30·38
Platinum	98·10	Lead	17·96
Silver	97·30	Marble	2·34
Copper	89·82	Porcelain	1·22
Iron	37·41	Brick-earth	1·13
Zinc	36·37		

The metals are evidently the best conductors; but even these differ remarkably, gold being 100, whilst lead has not one-fifth of the conducting property and power of transmitting molecular motion possessed by the first-named metal. Brick-earth is constituted of a number of distinct bodies; it is a mechanical mixture of a variety of compounds, each of which has an exact chemical composition. The particles are not only different from each other, but are widely apart; the substance is of a porous nature. Asbestos, pumice-stone, charcoal—and especially animal charcoal—sand, are all porous, and well-known bad conductors, so much so that a red-hot ball of iron can be held in the hand for a certain time, provided a layer of either of the above-named substances intervene between the skin of the hand and the heated metal.

By a more careful mode of experimenting, the conductivity of the various metals has been determined by Despretz, Wiedemann, and Franz. In this table it will be seen that silver occupies the first place, instead of gold, which is third. Platinum, again, which stands second in the first table, is very low down in the scale of conductivity; and bismuth is the lowest of all.

Silver	100	Iron	12
Copper	74	Lead	9
Gold	53	Platinum	8
Brass	24	German silver	6
Tin	15	Bismuth	2

Franklin and Igenhausz must therefore have committed some gross errors in their experiments, or the second table quoted here is wrong.

Dr. Tyndall explains the cause of the difference with a very pretty experiment. He takes a short prism of bismuth, and another of iron, of the same size, and having coated the extremities with wax, they are both placed on the lid of a vessel filled with boiling water. Strange to say, the wax on the bismuth melts *first*, although it has six times less conductivity than iron. Here is a paradox which requires explanation, and shows why the experiments conducted by Franklin and Igenhausz cannot agree with those of more modern physicists. In the first place, the test of conductivity employed by the earlier experimenters was the *rapidity* with which the wax and tallow coating a bar of any given substance melted in comparison with another—just as Tyndall used the prisms of bismuth and iron.

In the second place, the mode of experimenting employed by Despretz was not simply a determination of the rapidity with which the thermometer inserted in the bar was affected, as shown in

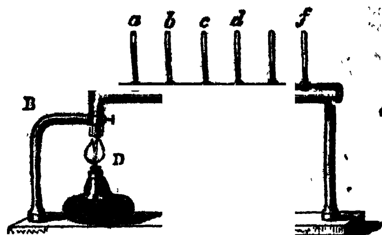


FIG. 160.—*Despretz's Mode of determining the Conductivity of Metals.*

A, the bar containing the thermometers, *a*, *b*, *c*, *d*, *e*, *f*; B, glass supporting A; D, the spirit-lamp.

but he waited until the bar showed a stationary condition of heat, and the thermometers no longer continued to rise, and, by estimating the difference between each thermometer, he soon discovered that the best conductors produced the least amount of difference between the thermometers, and that the worst conductor gave the contrary result.

Why did he wait until the heat of the bar became stationary?

To avoid the error caused by the difference of "specific heat," which varies with every substance. This difference is readily explained by the following experiments:

A pint of water at 50° F. mixed with a pint at 100° F. will amount to a quart, which will have a mean temperature of 75° F.

50° F.
100° F.
2)150
75° F.

Here the molecules are exactly the same; it is water mixed with water, and the particular heat required to raise any given bulk to a certain temperature cannot alter. If, however, a pint of water at 100° F. is mixed with a pint of mercury at 40° F., the resulting temperature is not the mean, 70°, but 80°; the water has only fallen 20°, whilst the mercury has risen 40°. The 20° of heat from the water has been sufficient to heat the mercury 40°. Hence it is apparent that mercury has a less "*capacity for heat*" (keeping to old expressions) than water, and it requires a smaller amount of heat to raise it to a given temperature, viz., 80°. For the term, "capacity of heat," or "specific heat," substitute, according to the dynamical theory, the term, "power to get into molecular motion," or "capacity for molecular motion."

We may once more return to Tyndall's paradox with the bismuth and iron. The "capacity for heat," or "specific heat," of iron is 0·1138; that of bismuth is only 0·0308: like the mercury and the water experiment, it takes less heat to warm any given mass of bismuth than it does to heat an equal bulk of iron.

The molecular motion which can be set up in bismuth occurs much quicker than it does in iron: one might almost say that the "inertia of heat" in iron was greater than that of bismuth. But this inertia once overcome, and each metal transmitting all the molecular motion which can be conferred from the vessel containing the boiling water, it will soon be found, according to the table quoted by Tyndall, that iron transmits six times more vibratory power, or motion of heat, than bismuth; it has less power to get into molecular motion than bismuth, but, once in motion, it sends vibration after vibration from molecule to molecule, and soon outstrips the bismuth in the race of conductivity.

In this place it is desirable to speak of certain terms which have arisen and are used in conformity with the dynamical theory of heat.

1.—"Potential" Force.

Potential force may be defined as a power waiting and ready to be used; "the sword of Damocles suspended by a hair;" the giant standing motionless, but capable, at the word of command, of exerting great physical power. It is, in short, stored-up energy—the gold in the bank cellars, potential, but not in circulation or use. Substitute for the word "force" heat, and you have potential heat.

2.—"Actual" Force, or "Energy."

As the first was dormant or passive, the second is "actual" or real, and makes itself apparent—the hair broken, the sword in the act of descending. They are mutually convertible: as actual heat appears, potential heat is used up and disappears. You cannot store gold in a cellar and use it at the same time.

The stored gold would represent potential heat; the gold in use or circula-

tion, actual heat. A country in a state of peace would have gold stored, and ready to pay an army; but the latter, once formed and in actual service, must be paid; and as the army becomes active, the potential energy—the gold—disappears.

One pound of hydrogen and eight pounds of oxygen contain potential energy which is enormous; when they unite, they form nine pounds of water, and the mechanical value of the heat, or actual energy, set free is equivalent to a force that would raise forty-seven millions of pounds weight one foot high.

The change of one pound of hydrogen, by combination with eight pounds of oxygen, into nine pounds of water would be an example of "chemical action."

Action and reaction are equal, but contrary; and therefore Dr. Odling's admirable lecture "On Reverse Chemical Action," delivered before the last

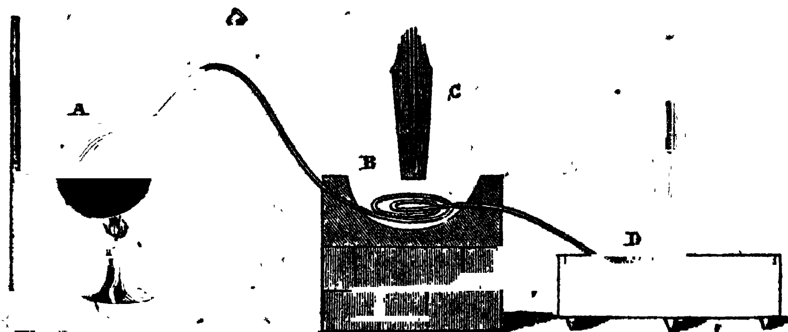


FIG. 161.

A, the flask of water boiled by spirit-lamp, and delivering steam to the platinum tube B, coiled round and placed in a hollow made in a firebrick, and subjected to the intense heat of the oxy-hydrogen blow-pipe C. D, small pneumatic trough and tube for collection of the two gases, oxygen and hydrogen.

meeting of the British Association, held at Norwich, is most welcome, because it supplies the reasoning for the opposite effect—viz., the conversion of "actual energy, or heat," into potential energy.

By passing the vapour of water through a spiral platinum tube, made white-hot by the oxy-hydrogen flame, the vapour is divided again into its elements, oxygen and hydrogen. This beautiful experiment, so worthy of the author of the "Correlation of the Physical Forces," Professor Groves, is shown at Fig. 161.

The platinum tube has no power to unite with the oxygen or the hydrogen; it is simply the vehicle for the application of the intense heat of the oxy-hydrogen blowpipe. The potential energy of the mixed gases produces actual energy or heat, and the latter again stores up potential energy by the reproduction of hydrogen and oxygen. Nothing can be more perfect as a train of experimental reasoning, or more decidedly illustrate the conversion of potential into actual energy, and *vice versâ*. It is a true illustration of "conservation of energy," and enables the student to realise the magnificent principle which destroys nothing, nor admits the destruction of anything, because throughout the universe the sum of these two energies, called "potential" and

"actual," is equal. The conclusion of Dr. Odling's brilliant address, "On Reverse Chemical Action," admirably expresses these grand truths:

"Reverse chemical actions are those which do not take place of themselves, but only by the application of some external force or agency, which force becomes as it were stored up in the product of the reaction; in other words, it is attended by a conversion of potential into actual energy. It is an instance of winding up, and not of running down. Direct chemical action takes place of itself by virtue not of an innate tendency of the bodies, which acts, but of an energy which has been put into the bodies at some time or other; it takes place of itself, and is attended by the liberation of pent-up forces contained in the reacting bodies,—in other words, it is attended by a conversion of potential into actual energy. Every direct chemical combination has been preceded by some reverse chemical action, just as the falling down of a weight has been preceded by the winding of it up. When we consume wood and coal in our fires, or bread and wine in our bodies, we merely effect a combination whereby their potential is converted into actual energy, this potential energy having been stored up in them at the period of their formation; this energy being, in fact, the robbing of the sun's rays, and the storing up the heat of these rays in these articles of fire and fuel. Under the action of the sun's rays the decomposition is effected of the carbonic acid and water into oxygen gas, restored to the atmosphere, and carbon-hydrogen, which is accumulated in the vegetable tissue. When we burn these tissues in our fires or bodies, we are simply restoring in the form of actual energy the potential heat of the sun's rays or its mechanical equivalent. We have all read of the *Bourgeois Gentilhomme* who had been talking prose all his life without knowing it. We have all our lives, and some of us without knowing it, been realising that celebrated problem of extracting sunbeams from cucumbers."

It should be mentioned that Wiedemann and Franz did not employ thermometers; they used a more refined arrangement with the thermo-electric pile and galvanometer needle—a most delicate measurer of heat, which will be more fully explained presently. Wool, chalk, stone, fire-clay, ivory, are all bad conductors of heat. Asbestos, powdered pumice-stone, charcoal, sawdust, and snow are still worse conductors of heat. The subdivision and pulverization of the substance increase porosity, and decrease conductivity. The wool and fur of animals, the plumage of birds, and especially the down (made into eider-down quilts), are all good examples of the wondrous care with which a superintending Creator has foreseen the various wants of the animal kingdom, and protected them even against the vicissitudes of temperature.

The kettle-holder made of wool, the pieces of ivory which break the metallic communication between the good-conducting silver teapot and its handle and the soot—charcoal—covering the bottom of a kettle, which allows the vessel to be taken direct from the fire and, though full of boiling water, held upon the palm of the hand, are good and familiar examples of the application of bad conductors.

One of the most interesting novelties displayed in the department devoted to Norway, in the French Exhibition of 1867, was the Self-acting Norwegian Cooking Apparatus, constructed in the most simple manner, of a wooden box lined with four inches of felt, in which the saucepans containing the food, previously boiled and maintained at the boiling-point for five or ten minutes, according to the nature of the food to be cooked, are placed. The heated

saucepans are covered with a thick felt cover, and, the lid of the box being fastened down, the rest of the cooking is done by slow digestion, no more heat being added.

The heated vessels containing the food will retain a high temperature for several hours, so that a dinner put into the apparatus at 8 in the morning would be quite hot and ready by 5 in the afternoon, and would keep hot up to 10 or 12 at night, because the felt clothing so completely prevents the escape of the heat; and as the whole is enclosed in a box, there are no currents of air to carry off any other heat by convection.

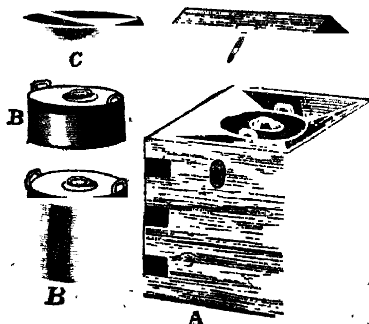


FIG. 162.—*The Norwegian Self-Acting Coo[illegible]ratus.*

A, the box, lined with felt; B B, saucepans fitting into box; C, the [illegible]r to be placed on the top of the saucepans.

The principle on which this cooking apparatus acts is that of retaining the heat; and it consists of a heat-retainer or isolating apparatus shaped somewhat like a refrigerator, and of one or more saucepans or other cooking-vessels made to fit into it. Whereas in the ordinary way of cooking the fire is necessarily kept up during the whole of the time required for completing the cooking process, the same result is obtained, in using this apparatus, by simply giving the food a start of a few minutes' boiling, the rest of the cooking being completed by itself in the heat-retainer away from the fire altogether.

Directions for use.—Put the food intended for cooking, with the water or other fluid *cold*, into the saucepan, and place it on the fire. Make it boil, and when on the point of boiling skim if required. This done, replace the lid of the saucepan firmly, and let it continue boiling for a few minutes. After the expiration of these few minutes, take the saucepan off the fire, and place it immediately into the isolating apparatus, cover it carefully with the cushion, and fasten the lid of the apparatus firmly down. In this state the cooking process will complete itself without fail.

By no means let the apparatus be opened during the time required for cooking the food.—The length of time which the different dishes should remain in the isolating apparatus varies according to their nature. It may, however, be taken as a general rule that the same time is required to complete the cooking in the apparatus as in the ordinary way on a slow fire.

The advantages of this apparatus are thus detailed by Herr Sörensen, the patentee, whose attention was first directed to the subject by the Norwegian

peasants, who heat their food in the morning, and whilst away in the fields, keep the saucepan hot by surrounding it with chopped hay:

1. *Economy of Fuel* varies according to the length of time required for cooking the different sorts of food. For those requiring, in the ordinary way, only one hour's cooking, the saving is about 40 per cent.; two hours, 60 per cent.; three hours, 65 per cent.; six hours, 70 per cent. In the case of gas being used, the saving would be greater still.

2. *Economy of Labour.*—A few minutes' boiling is sufficient. No fire is necessary afterwards. The cooking-pot once in the apparatus, the cooking will complete itself. Over-cooking is simply impossible, and the process of cooking is infallible in its result. The food will be cooked in about the same time as if fire had been continuously used. But the food need not be eaten for many hours after the cooking process is complete; so that half-an-hour's use of a fire on a Saturday night, for example, will give a smoking hot dinner on Sunday.

3. *Portability.*—The weight of the apparatus complete varies from 18 to 50 lbs. The apparatus can, in proportion to its dimensions, be carried about with great facility, without interfering with the cooking process. By means of a large apparatus—for instance, following on a cart a detachment of soldiers on the march—it is possible to provide them with a hot meal at any moment it might be found convenient (as may be proved by official reports from the officers of the Royal Guard at Stockholm, in the possession of the patentee). Again, fishermen, pilots, and others whose small vessels are not generally so constructed as to enable them to procure hot food while at sea, may easily do so, by taking out with them in the morning an apparatus prepared before their departure. It is, in short, a thing for the million, for rich and poor; for the domestic kitchen, as well as for persons away from their homes. It cooks, and keeps food hot, just as well when carried about on a pack-saddle, on a cart, or in a fisherman's boat, as in a coal-pit or under the kitchen table.

4. *Quality and quantity of the food prepared.*—Where other plans of cooking waste one pound of meat, this apparatus, properly used, wastes about one ounce. The unanimous testimony of those who have used it pronounces the flavour of food cooked in this manner incomparably superior to that which is ordinarily produced.

5. *Simplicity of use.*—One of the greatest advantages of this invention is, no doubt, its simplicity and practical application. There is no complication of hot-water or air pipes to retain the heat, no mechanical combination whatever for producing a high degree of heat by steam pressure; consequently there is no necessity for steam-valves or other combinations which would render the use of the apparatus difficult and dangerous. Any person will, without difficulty, be able to use the apparatus to advantage after once having witnessed it in operation. No special arrangement is required in the kitchen for using the apparatus. Any fuel will do for starting the cooking.

6. In addition to all these advantages, the complete apparatus constitutes the 'Simple Refrigerator' for the preservation of ice, which has attracted so much notice (see Letters in *Times*, July 30, 31, August 4, 1868), and had such warm approval from medical men. It will keep ice in small quantities for many days.

In the organization of our bodies there are chemical changes going on which maintain a certain temperature. It matters not whether the living being, man, is a resident of tropical or polar regions; the temperature required

to promote and carry on vitality remains the same, or nearly so. If the cold or absence of heat is likely to be dangerous, man uses the skins and furs of animals for his clothing, and takes care to lose little or no heat. On the other hand, if the heat is excessive, increased action of certain powers throws out perspiration, which carries off the heat that might accumulate and prove dangerous. Solid bodies convey their heat rapidly to the human body, and the reverse. Somebody said that a frog could not be killed by any extreme of cold; but when the animal was carefully dressed in tinfoil and then subjected to the cold produced by a freezing mixture, the conducting power of the metal was too much for the animal powers of the frog to resist, and he was killed. The air during the summer months is often very hot—upwards of 100° F. in the glare of the sunlight; but the heat from air is very slowly communicated to the body, and the latter has time to neutralize the otherwise burning heat by consuming it in work, *i. e.*, by forcing water through the pores of the skin, and converting it in part into vapour.

The very low conductivity of the gases is shown by some very interesting experiments, performed by Tillet in France, and by Dr. Fordyce and Sir Charles Blagden and others in England, and thus related by Sir David Brewster in his charming little book called "Letters on Natural Magic:"

"Sir Charles Blagden, Dr. Solander, and Sir Joseph Banks entered a room in which the air had a temperature of 198° F., and remained ten minutes; but, as the thermometer sank very rapidly, they resolved to enter the room singly. Dr. Solander went in alone, and found the heat 210° F., and Sir Joseph entered, when the heat was 211° F. Though exposed to such an elevated temperature, *their bodies preserved their natural degree of heat.* Whenever they breathed upon a thermometer, it sank several degrees: every expiration, particularly if strongly made, gave a pleasant impression of coolness to their nostrils, and their *cold breath* cooled their fingers whenever it reached them.

"On touching his side, Sir Charles Blagden found it *cold like a corpse;* and yet the heat of his body, under his tongue, was 98° F.

"Hence they concluded that the human body possesses the power of destroying a certain degree of heat when communicated with a certain degree of quickness. This power, however, they concluded, varied in various media.

"The same person who experienced no inconvenience from air heated to 211° could just bear rectified spirits of wine at 130°, cooling oil at 129°, cooling water at 123°, and cooling quicksilver at 117°. A familiar instance of this occurred in the heated room. All the pieces of metal there, even their watch-chains, felt so hot that they could scarcely bear to touch them for a moment, while the air from which the metal had derived all its heat was only unpleasant.

"Messrs. Duhamel and Tillet observed, in France, that the girls who were accustomed to attend ovens in a bakehouse were capable of enduring for ten minutes a temperature of 270°.

"The same gentlemen who performed the experiments above described ventured to expose themselves to a still higher temperature.

"Sir Charles Blagden went into a room where the heat was 1° or 2° above 260° F., and remained eight minutes in this situation, frequently walking about to all the different parts of the room, but standing still most of the time in the coolest spot, where the heat was above 240° F.

"The air, though very hot, gave no pain, and Sir Charles and all the other gentlemen were of opinion that they could have supported a much greater heat.

"During seven minutes Sir C. Blagden's breathing remained perfectly good; but after that time he felt an oppression in his lungs, with a sense of anxiety, which induced him to leave the room. His pulse was then 144—double its ordinary quickness.

"In order to prove that there was no mistake respecting the degree of heat indicated by the thermometer, and that the air which they breathed was capable of producing all the well-known effects of such a heat on inanimate matter, they placed some eggs and a beef-steak upon a *tin frame*, near the thermometer, but more distant from the furnace than from the wall of the room. In the space of twenty minutes the eggs were roasted hard; and in forty-seven minutes the steak was not only dressed, but almost dry. Another beef-steak similarly placed was rather over-done in thirty-three minutes. In the evening, when the heat was still more elevated, a third beef-steak was laid in the same place, and, as they had noticed that the effect of the hot air was greatly increased by putting it in motion, they blew upon the steak with a pair of bellows, and thus hastened the cooking of it to such a degree that the greatest portion of it was found to be pretty well done in thirteen minutes.

"Sir Francis Chantrey, the late eminent sculptor, exposed himself to a temperature still higher than any yet mentioned.

"The furnace he employed for drying his moulds was about 14 ft. long, 12 ft. high, and 12 [illegible] d. When raised to its highest temperature with the doors closed, the [illegible] r stood at 350° F., and the iron floor was red hot. The workmen [illegible] at a temperature of 340°, walking over the iron floor with wooden c[illegible] had become charred on the surface. On one occasion Sir Francis, a[illegible] by five or six of his friends, entered the furnace, and, after remaining [illegible] tes, they brought out a thermometer which stood at 320°. Some of the [illegible] experienced sharp pains in the tips of their ears and in the septum of the nose, while others felt a pain in their eyes."

In this very interesting account we see it was assumed by the observers that the power of resisting the high temperature was due to some natural power or vitality, and yet it is stated that the tips of the ears and the septa of the nose were painfully affected. Certainly a live body resists a heat that would cook a dead one; therefore, in the abstract, vitality or the maintenance of the various processes inseparable from the living being, must not be wholly disregarded, as without vitality none of those changes of matter could occur which enable the living tissues to resist the great heat; but, after all, the "actual" heat is converted into "potential" heat, perspiration is secreted and escapes from the natural outlets of the body, the pores of the skin, and the lungs. Time, of course, is an important element in these experiments, and even the living body must succumb to any lengthened application of the great heat already described.

Heated gases impart their heat very slowly to surrounding objects, because the gases are bad conductors of heat. If, for the sake of discussion, we could imagine an atmosphere composed of minute and rare atoms of silver, such an atmosphere, if it could be breathed, would impart its heat with dangerous rapidity to the body.

Liquids, like gases, conduct heat very slowly. The hand may be placed within a short distance of a quantity of boiling water, and is wholly unaffected by its dangerous neighbour. The experiment is easily tried by first placing round a cylindrical glass, that will easily admit the hand, a large tube of caoutchouc.

The large tube can be made in the usual manner, by cutting the edges of the sheet of caoutchouc first, and then winding it twice or thrice round some cylindrical vessel; the whole, being kept together with tape, is then boiled and allowed to cool; a large india-rubber tube is then obtained, which can be stretched over one end of the glass cylinder and properly fixed with string; the hand is then inserted, and the india-rubber tube tied round the wrist.

The glass, containing the hand, is now held upright, and cold water poured in, so that the clenched hand is covered with one inch of water. Some boiling



FIG. 163.—*The Hand placed in Water which is boiling above it.*

A, section of glass cylinder, made a little funnel-shaped at the top, with the caoutchouc tube B B attached by string to the lower part; C C, apparatus attached to the arm, and tied round tightly, so that the water cannot escape: this must be carefully attended to, because if the cold water runs away the boiling water will come down upon and scald the hand; D, the red hot iron (the half of a dumb-bell with a hole bored through it) held by a hook.

water, coloured with a solution of indigo, is now carefully poured in down the sides of the glass, or, better still, on a thin disc of cork, floating on the cold water above the hand. The line of demarcation is readily seen by the difference between the colourless cold and the coloured hot water. A red-hot ball, held by a hooked iron, is now applied to the top of the coloured water, which will soon enter into a violent state of ebullition: the water boils at the top, but does not communicate its heat by conduction downwards to the hand.

After the experiment has been tried, of course the arm must not be reversed to pour out the water, or else the hand may be scalded. A syphon, protected by a fold of flannel or paper, may be filled with cold water in the usual way,

and the boiling water run off quickly. If the syphon was not covered with some bad conducting substance, the person helping to run off the boiling water might be inclined to leave go, when the hand inside would run a great risk of feeling the temperature of boiling water. It is, of course, one of those experiments which succeed thoroughly if all the manipulations are properly carried out from the beginning to the end.

Another and very delicate proof of the bad conductivity of water can be shown by fixing a differential thermometer in a cork placed in the mouth of an inverted gas jar, and then heating the water at the top with a red-hot iron.

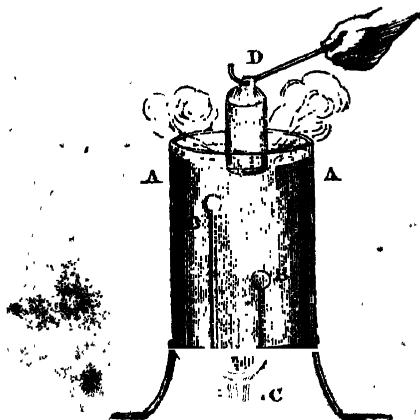


FIG. 164.

A A, inverted gas jar with neck C stopped with a good cork, through which the stem attached to the differential thermometer B B passes. The jar is filled with cold water, and heated from the top by a common urn-heater, D.

Although the thermometer is unaffected, it does not follow that water will not conduct heat. M. Despretz has ascertained that water will conduct heat very slowly. The motion of the particles which is immediately set up when the water is heated from the top must tend to destroy that similarity of molecules which seems so desirable to secure good conductivity.

Directly any portion of the water is heated, its gravity is altered, and it becomes lighter; this perpetual-motion of the individual particles must interfere with the steady propagation of dynamical force, which has been shown to be essential to good conductivity. It appears to be doubtful whether gases do conduct heat: the molecules are too wide apart, and have greater mobility than liquids. Both with liquids and gases, circulation is a necessary condition if either are to be warmed, and hence, in speaking of the application of heat to these forms of material substances, another term is employed, viz., "convection," or carrying power.

To heat a vessel of water to the boiling-point, the fire must be applied at the bottom; a circulation of particles immediately commences; the expanded or lighter particles rise by reduced specific gravity to the top, and, as they travel upwards, convey the heat "by convection" through the other and colder

particles, which descend to take their place, and thus a constant circulation is set up until the whole is brought to one temperature, viz., the boiling-point, 212° F.

When Sir Joseph Banks and others experimented with the atmosphere heated to 260°, they found that if the heated air was set in motion and caused to travel rapidly, with the aid of the bellows, over the skin, the heat soon became disagreeable, and with dead matter (the beef-steak), at a higher temperature, it was distinctly shown that the process of cooking was more rapidly carried on when the hot air was kept in motion and its carrying power made use of.

The same fact was observed by the Arctic discoverers, who could bear the most intense cold, viz., minus 55°, or 14° below the freezing-point of mercury, when the air was still; but, if set in motion, the wind, the current of air, or the cold blast dangerously affected the extremities, which were rapidly deprived of heat by this power of convection, and frozen or "frost-bitten."

In all schemes for ventilating and supplying heated air, circulation must, of course, be maintained, either to impart or carry off heat.

It is said that, if the hand is kept perfectly still in water heated to a temperature of 150° F., the nerves are not disagreeably affected; but directly the hand is moved, then the heat becomes painful, and cannot be borne.

As an illustration of convection, or the carrying of heat, on the grand scale, there are the trade winds and the Gulf Stream.

In the tropics the heated earth imparts some of its [illegible] to great volumes of air, which ascend and flow towards the poles; upper currents from the equator to the poles must be succeeded by under currents from the poles to the equator.

The constantly ascending warm air is thus a carrier of heat to colder climates, and *vice versâ*. These currents are modified by the various physical conditions of the earth's surface.

In like manner, a great current of warm water, which leaves the Straits of Florida at a temperature of 83° F., passes across the Atlantic in a north-easterly direction. It washes the north-western shores of Europe, and makes itself, or rather its heat-giving power, apparent by flowing round the coast of Ireland. In mild winters in England it is the diffusion of heat by certain winds, and the good offices of the Gulf Stream, which mitigate the severity of the season; and these carriers of heat are only neutralized when similarly, but contrarily, enormous masses of ice, icebergs, are detached from the polar regions, and rob the water of its heat on its journey to our shores.

LATENT HEAT.

Capacity for Heat—Specific Heat—Heat of Atoms—Atomic Heat.

These somewhat difficult terms or titles, referring to truths that the young student does not, perhaps, fully appreciate at first, nay, to speak plainer, which he never will comprehend without industrious application to study, are set forth in the following chapters.

In all the old standard works upon natural philosophy it is usual to state that there are two kinds of heat that may be resident in a body, viz., one kind

called "sensible heat," which is designated as temperature, and is capable of measurement by the thermometer and other kindred instruments; another and more subtle condition, not apparent to our nervous system, called "latent heat," and incapable, whilst in that condition, of affecting any measurer or test of "sensible heat." The dynamical theory substitutes the terms "actual energy," or force, for that of "sensible heat," and "potential energy" for that of "latent heat."

The one, actual heat or energy, is in use; the other, potential heat or energy, is in store. A horse-shoe nail may be warmed by any convenient source of heat, and as long as it remains above the temperature of the air we have evidence of "actual heat."

When cold it may be hammered on an anvil, by an expert blacksmith, and then becomes so hot it will set fire to sulphur or phosphorus. The heat thus evoked was formerly called "latent heat," and was supposed to be combined with the material substance of the iron; the dynamical theory rejects the idea of its being a distinct subtle fluid, but ascribes the heat to the motion of the particles of the iron. It may be useful here to tabulate the new terms used by Clausius, Rankin, Tyndall, and others, in their exposition of the dynamical theory of heat.

ENERGY OR HEAT.

Defined to be the power of performing work. It may be *latent* or *sensible.*

Latent.	*Sensible.*
Possible energy, or work to be done.	Actual energy, or work is being done.
Potential energy is energy in store.	Dynamic energy is energy in action.

One column of terms is the exact antithesis of the other. There is no mechanical machine by which we can tear asunder or separate the ultimate molecules of bodies. Cohesion, or molecular force, is too potent to be overcome by mechanical energy. Heat, another kind of energy, will, however, act where the former fails; therefore heat is the equivalent for mechanical energy.

When a metal is expanded by heat, every molecule is separated or forced asunder; the energy of heat must be enormous to overcome the force of cohesion. When a mass of metal is heated, there is not only the motion imparted—the vibratory power set up to produce sensible or actual energy (heat)—but the molecules or atoms of the metal are pushed asunder, as shown by their expansion. This work, which goes on inside and throughout the mass of the metal, is not visible, and therefore may be called "interior work."

Tyndall compares this *interior work* to the raising of a weight from the earth—the overcoming of the force of gravity, which attracts all things, and keeps all terrestrial bodies in their places. The raising of a weight by a cord from the earth, it is clear, confers "a motion-producing power." The weight can fall, and in its descent can perform work. Whilst hanging in the air, it represents possible energy, or "potential" energy.

The pull, or attraction of gravity, causes this possible or "potential" energy. If there were no attraction between the substance and the earth, there would be no "possible" energy.

Substitute the ultimate atoms of bodies for the weight and the earth

remember that the atoms of solid bodies are held together with molecular force (cohesion), and it must be evident that whenever they are separated, although the distance to which they are separated cannot be measured—it is too minute—still the fact remains, and when the atoms come together it is like the fall of the weight to the earth, and the result must be the production of actual energy, or heat.

This is what Tyndall means when he speaks of the clashing together of the atoms.

The heating of the cold horse-shoe nail by hammering, or the heating of cold bars by rolling, is simply the conversion of mechanical energy into molecular motion; if the approach of the molecules of a body will produce actual energy, a still nearer approach must increase that energy, or heat. Indeed, the experiment already quoted, of heat produced by hammering and bringing the atoms nearer together, is a good illustration of the above argument.

The "specific heat" (a term that must be carefully considered presently) of a metal like copper is altered when a nice, soft, well-annealed piece is hammered: heat is produced, and the specific heat changes from 0·09501, 0·09455, to 0·09360, 0·09330; and its specific gravity or density becomes higher. When again heated red hot and allowed to cool slowly, as is done in the process of annealing, its specific heat returned to 0·09493, 0·09479, or very nearly the same that it was at first. Thus by alternately hammering and then heating or annealing a metal, the atoms are brought more closely together or pushed further apart. When the atoms are pushed further apart, the heat becomes potential or latent; when advanced nearer to each other, the heat is actual or sensible. Nearly every philosopher selects a particular subject to which he devotes his special attention. Let us read what Dr. Tyndall says of latent heat in his standard work, "Heat a Mode of Motion."

"We shall now direct our attention to the phenomena which accompany *changes of the state of aggregation*. When sufficiently heated, a solid melts; and when sufficiently heated, a liquid assumes the form of gas. Let us take the case of ice, and trace it through the entire cycle. This block of ice has now a temperature of 10° C. below zero. I warm it; a thermometer fixed in it rises to 0°, and at this point the ice begins to melt; the thermometric column, which rose previously, *is now arrested in its march, and becomes perfectly stationary*. I continue to apply warmth, but there is no augmentation of temperature; and not until the last film of ice has been removed from the bulb of the thermometer, does the mercury resume its motion. It is now again ascending; it reaches 30°, 60°, 100° C.; here steam-bubbles appear in the liquid; it boils, and, from this point upwards, *the thermometer remains stationary at* 100°. But during the melting of the ice, and during the evaporation of the water, heat is incessantly communicated. To simply liquefy the ice, as much heat is imparted as would raise the same weight of water 79·4° C., or as would raise 79·4 times the weight one degree in temperature; and to convert a pound of water at 100° C. into a pound of steam at the same temperature, 537·2 times as much heat is required as would raise a pound of water one degree in temperature. The former number, 79·4° C. (or 143° F.), represents what has been hitherto called the *latent heat* of water; and the latter number, 537·2° C. (or 967° F.), represents the latent heat of steam.

"It was manifest to those who first used these terms, that throughout the entire time of melting, and throughout the entire time of boiling, heat was

communicated; but inasmuch as this heat was not revealed by the thermometer, the fiction was invented that it was rendered latent. The fluid of heat was supposed to hide itself in some unknown way in the interstitial spaces of the water and the steam.

"According to our present theory (the dynamical), the heat expended in melting is consumed in conferring potential energy upon the atoms: it is virtually the lifting of a weight. So likewise as regards steam, the heat is consumed in pulling the liquid molecules asunder—conferring upon them a still greater amount of potential energy.

"When the heat is withdrawn, the vapour condenses, the molecules again clash with a dynamic energy equal to that which was employed to separate them, and the precise quantity of heat then consumed now re-appears.

"The act of liquefaction consists of *interior work* expended in moving the atoms into new positions. The act of vaporization is also, for the most part, *interior work;* to which, however, must be added the exterior work of forcing back the atmosphere, when the liquid becomes vapour. . . . . . Let us then fix our attention upon this wonderful substance, water, and trace it through the various stages of its existence. First, we have its constituents as free atoms of oxygen and hydrogen, which attract each other, fall or clash together. The mechanical value of this atomic act is easily determined. The heating of 1 lb. of water 1° C. is equivalent to 1,390 foot-pounds; hence the heating of 34,000 lbs. of water 1° C. is equivalent to 34,000 × 1,390 foot-pounds.

"We thus find that the concussion of our 1 lb. of hydrogen with 8 lbs. of oxygen is equal, in mechanical value, to the raising of forty-seven million pounds one foot high.

"I think I did not overstate matters when I stated that the force of gravity, as exerted near the earth, is almost a vanishing quality, in comparison with these molecular forces.

"The distances which separate the atoms before combination are so small as to be utterly immeasurable; still it is in passing over these spaces that the atoms acquire a velocity sufficient to cause them to clash with the tremendous energy indicated by the above numbers. After combination, it is in a state of a vapour, which sinks to 100° C., and afterwards condenses into water. In the first instance the atoms fall together to form the compound; in the next instance the molecules of the compound fall together to form a liquid. The mechanical value of this act is also easily calculated. 9 lbs. of steam, in falling to water, generate an amount of heat sufficient to raise 537·2 × 9 = 4,835 lbs. of water 1° C., or 967 × 9 = 8,703 lbs. 1° F. Multiplying the former number by 1,390, or the latter by 772, we have in round numbers a product of 6,720,000 lbs. as the mechanical value of the mere act of condensation.

"The next great fall is from the state of liquid to that of ice, and the mechanical value of this act is equal to 993,564 foot-pounds. Thus our 9 lbs. of water, at its origin and during its progress, falls down three great precipices; the first fall is equivalent in energy to the descent of a ton weight down a precipice 22,320 feet high; the second fall is equal to that of a ton down a precipice 22,900 feet high; and the third is equal to the fall of a ton down a precipice 433 feet high.

"I have seen the wild stone-avalanches of the Alps, which smoke and thunder down the declivities with a vehemence almost sufficient to stun the

observer. I have also seen snow-flakes descending so softly as not to hurt the fragile spangles of which they were composed; yet to produce from aqueous vapour a quantity, which a child could carry, of that tender material, demands an exertion of energy competent to gather up the shattered blocks of the largest stone-avalanche I have ever seen, and pitch them to twice the height from which they fell."

Capacity for Heat.

This term, which is most simple and useful, expresses a fact that has been forced upon observers by numerous experiments made with the thermometer. The thermometer is usefully applied to determine the temperature of any solid, fluid, or gaseous matter; but it will not tell the observer how much heat or actual energy is contained in different measures of the same fluid. A gallon of water in one vessel, and a pint of water in another, may be shown by the thermometer to have a temperature of 212° F.; but the quantity of energy or heat must be much greater in the larger measure—the one gallon—than in the single pint. The thermometer fails to show the quantity of energy, whilst it gives relatively the "relative actual heat"—the "temperature." A photometer, or measurer of light, will demonstrate the relative illuminating power of any given source of light; but it cannot give the number of vibrations per second producing the light. A thermometer can tell us truthfully how much hotter or colder than 32° or 212° F. a substance may be; but it cannot inform us what may be the amount of vibratory power given, and the molecular force detached, which, according to the dynamical theory, must be the equivalent for the expression or quantity of heat. There are certain facts, explain them how we will, which are indisputable. If 10 lbs. of water (one gallon) at 100° F. are mixed with the same weight of oil at 50° F., the resulting temperature will not be the mean, 75° F., but $83\frac{1}{3}$° F. The water, therefore, has lost "actual energy" equal to $16\frac{2}{3}$; but the same energy has caused the oil to rise $33\frac{1}{3}$.

If the experiment is reversed, and 10 lbs. of oil at 100° are mixed with 10 lbs. of water at 50°, the mean will be $66\frac{2}{3}$°: the $33\frac{1}{3}$° actual heat or energy given out from the oil is only able to raise the temperature of the water $16\frac{2}{3}$°.

The actual energy which will raise the temperature of oil 2° will raise an equal quantity of water only 1°. The heat that will raise any given substance from 0° C. to 1° C., compared with the amount of "energy" required to heat an equal weight of water to the same point, is called its "specific heat." Therefore the specific or potential heat of oil will be a half, ·5, as compared with the unit or one—viz., water.

As the oil has been quickly heated, so it will rapidly cool; it has only half the "energy of heat" possessed by water to give up. If the water require one hour to cool to any given temperature, the oil would reach the same point in half-an-hour.

Hence "time" is the test used sometimes to determine the specific heat of bodies—the time required by a substance to cool. Or the process may be reversed by ascertaining the quantity of ice which exactly equal weights of other bodies can melt in falling from one temperature to another, say from the boiling-point to the freezing-point of water. As the process of mixture already described with the oil and water may be employed, there are therefore three methods by which the specific heat of bodies may be determined:—

1. The direct method by mixture.
2. Time required to cool, and rate of cooling.
3. Heating of ice, and quantity liquefied by a given weight of the substance heated to 212° whilst falling to 32°.

By the first method—viz., mixture or immersion—the distinguished physicist, Regnault, arrived at the following results:

SPECIFIC HEATS OF EQUAL WEIGHTS BETWEEN 0° C. AND 100° C.

Water	1·00000	Brass	0·09391
Oil of turpentine	0·42593	Silver	0·05701
Charcoal	0·24150	Tin	0·05623
Glass	0·19768	Mercury	0·03332
Iron	0·11379	Platinum	0·03243
Zinc	0·09555	Gold	0·03244
Copper	0·09515	Lead	0·03140
Aluminium	0·21430	Bismuth	0·03080

For a lecture-table experiment there are none better than that devised by Tyndall, to show the time required by equal spheres of various solids, heated to the same temperature, to melt their way through a cake of beeswax.

The metals used are iron, lead, bismuth, tin, copper: these are shaped as balls or spheres, and each furnished with a hook for conveniently removing them from the oil in which they are heated to a temperature of 180° C.

A framework of wood, shaped like the spokes of a wheel, with five strings, to which the balls are attached, may be used in order to remove the whole of the balls at once from the heated oil.

When they are laid upon a cake of beeswax, 6 in. in diameter and half an inch thick, supported on the ring of a tripod or other convenient means of support, the iron and the copper balls go through first, the tin next, while the lead and bismuth are retained. If they contained the same amount of heat, or had the same "actual energy," they would all go through the wax in the same time: the difference in their specific heats determines the rate at which they perforate the wax.

Messrs. Dulong and Petit have shown that the specific heat of bodies increases as their temperature rises. Any given substance will require more heat to raise it a certain number of degrees when at a high than at a low temperature. The variations of specific heat according to temperature are well shown in the case of iron.

SPECIFIC HEAT OF IRON (DULONG AND PETIT).

From 32° to 212°	0·1098
" " 392°	0·1150
" " 572	0·1218
" " 666	0·1255

In a similar manner the specific heat of the gases has been carefully determined, the methods employed involving one of the three modes already described. De la Roche and Berard caused a measured volume of the gas under examination, when heated to a fixed temperature and kept at a uniform heat, to pass through a spiral glass tube surrounded with water (this plan would be equivalent to the "mixture" of oil and water), and, by observing the increase of the temperature of the water surrounding the spiral tube, and other data, they determined the specific heat of certain gases.

Dr. Apjohn devised another method, viz., that of vaporizing water by a current of the heated gases, and, by inverse proportion, viz., the greater the specific heat of the gas, the less time required to cool it, and *vice versâ*, he has given the specific heats of gases already examined by De la Roche; but unfortunately the figures of the two experimentalists did not agree, and therefore a more careful investigation was made by Regnault, who, taking the specific heat of an equal weight of water as the unit of comparison, commences with air, and gives the following table of the specific heats of a number of gases and vapours with which he experimented; and, what is still more valuable, the table gives the specific heat of equal volumes and weights of the bodies examined:

SPECIFIC HEAT OF GASES AND VAPOURS.

GAS OR VAPOUR.	Equal		GAS OR VAPOUR.	Equal	
	Vols.	Weight.		Vols.	Weight.
Air	0·2375	0·2375	Sulphurous anhydride	0·341	0·1540
Oxygen	0·2405	0·2175	Hydrochloric acid	0·2352	0·1842
Nitrogen	0·2368	0·2438	Sulphuretted hydrogen	0·2857	0·2432
Hydrogen	0·2359	3·4090	Water	0·2989	0·4805
Chlorine	0·2964	0·1210	Alcohol	0·7171	0·4534
Bromine	0·3040	0·0555	Wood spirit	0·5063	0·4580
Nitrous oxide	0·3447	0·2262	Ether	1·2266	0·4796
Nitric oxide	0·2406	0·2317	Ethyl chloride	0·6096	0·2738
Carbonic oxide	0·2370	0·2450	Ethyl bromide	0·7026	0·1896
Carbonic anhydride	0·3307	0·2163	Ethyl disulphide	1·2466	0·4008
Carbonic disulphide	0·4122	0·1569	Ethyl cyanide	0·8293	0·4261
Ammonia	0·2996	0·5084	Chloroform	0·6461	0·1566
Marsh gas	0·3277	0·5929	Dutch liquid	0·7911	0·2293
Olefiant gas	0·4106	0·4040	Acetic ether	1·2184	0·4008
Arsenious chloride	0·7013	0·1122	Benzol	1·0114	0·3754
Silicic chloride	0·7778	0·1322	Acetone	0·8341	0·4125
Titanic chloride	0·8564	0·1290	Oil of turpentine	2.3776	0·5061
Stannic chloride	0·8639	0·0939	Phosphorous chloride	0·6386	0·1347

Regnault's experiments confute those of De la Roche and Berard, and deny that the specific heat of air and all gases rises with the *temperature*. Regnault's experiments were carried on with air between the limits of temperature expressed by 30° C. and 200° C. The same result was obtained with gases like hydrogen, which cannot be easily liquefied; and the specific heat was not found to increase with the temperature, at least between 30° C. and 200° C. A gas which can be easily condensed, such as carbonic acid, shows, in accordance with the statement of De la Roche and Berard, an in specific heat with an increased temperature.

SPECIFIC HEAT OF CARBONIC ACID AT DIFFERENT TEMPERATURES.

Between — 30° and	8° C.	. . . specific heat	0·18427
— 8°	100°	. . „ „	0·20248
8°	210°		0·21692

Regnault also discovered that the specific heat of a given volume of a gas increases directly as its *density* is increased; and his valuable experiments show that the specific heat of the same liquid varies with the temperature.

There exists a remarkable connection between specific heat and atomic weight, which has given rise to another term—"atomic heat." This expression means the product obtained by multiplying the specific heat of a body by its atomic weight.

The specific heat of an elementary body is inversely as its combining proportion. Regnault discovered in upwards of twenty bodies chemically pure, that the atomic heat ranged between 3·31 and 2·93, giving a mean of 3·13. Hence, if the above number 3·13 is divided by the number expressing the specific heat of iron, lead, mercury, tin, &c., the quotient gives very nearly the atomic weight of the metal.

The term "atomic weight" must not be confounded with the term "chemical equivalent:" the latter is obtained by direct experiment, and means the combining proportion of the various elements, as, for instance, 1 being taken as the combining proportion or equivalent for hydrogen, 16 will be that of oxygen; or 1 of hydrogen may displace 65 of zinc; hence the former is equivalent to the latter.

Atomic weight is a product arrived at by calculations carried out in various ways, as, for instance, when the number 3·13 is divided by the specific heat of a metal.

Atomic weight is also arrived at by other methods; it may sometimes coincide with the combining proportion, or equivalent number, or it may be a multiple of it.

"Actual energy" (heat) disappears during liquefaction. When matter passes from the solid to the liquid state, "actual" is converted into "potential energy;" and the heat is said to disappear, and cold is produced. It is the enormous amount of actual heat, so slowly converted into potential heat, that prevents the sudden liquefaction of ice or snow, and the great damage which would occur to property if the snow could be quickly melted. Conversely, when a liquid is changed to the solid state, the closer proximity of the molecules, the merging together of the particles by cohesion, converts the "potential" into "actual" heat; and thus the very change of water into snow or ice produces actual energy, or heat, and helps to mitigate the effect of a sudden frost.

Taking the fact (irrespective of theory) that liquefaction will produce cold, there are various solids and mixtures of solids which will produce a sufficiently low temperature, when quickly dissolved in water, to freeze water contained in a vessel surrounded with the mixture. The mere solution of nitre alone will lower the temperature of water from 50° to 35° F. Four ounces of nitre and four ounces of common sal ammoniac dissolved in four ounces of water reduce the temperature from 50° F. to 10° F. A mixture of equal parts of snow, or powdered ice, and salt will sink the thermometer from 32° F. to 0°, or 32 degrees below the freezing-point of water; and two of snow and one of salt reduce the temperature to — 4° F. A mixture of three parts by weight of

chloride of calcium and two of snow will reduce the temperature from 32° F. to —50° F.; and by powdering and carefully cooling the chloride to 32° F., and using very thin vessels, mercury can be frozen. The liquefaction of a metallic alloy, composed of

207 parts by weight of lead,
118 " " tin,
284 " " bismuth,

in 1,617 parts of mercury, will sink the thermometer from 63° to 14°; and, of course, water can be frozen by this process.

One of the most interesting experiments is that of Mousson, who contrived an apparatus by which ice was subject to a pressure equal to thirteen thousand atmospheres, and by which its bulk was reduced by thirteen-hundredths of that which it occupied at 0° C. (32° F.).

The temperature of the ice was first reduced — 20° C. (—4° F.), and then subjected to the pressure of a copper rod, worked by a very powerful screw.

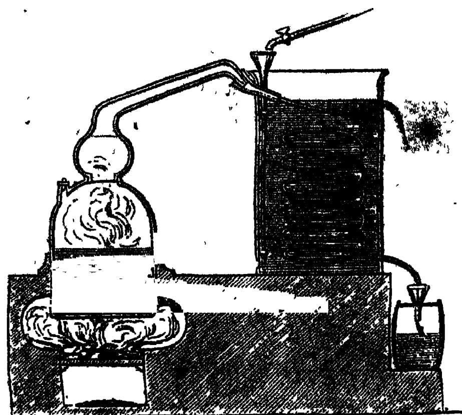


FIG. 165.—*A Still, with "Still Head," and the Worm surrounded by Cold Water.*

Instead of increasing the solidity of the ice, the mechanical compression and motion of the molecules liberated the equivalent in actual energy or heat; the ice liquefied, and the copper rod was found to have fallen to the bottom of the water, which again solidified directly the pressure was removed.

The freezing-point of water is lowered to a minute extent by pressure.

A liquid alloy of sodium and potassium is easily obtained by pressing pieces of the two metals together: if this liquid be brought into contact with mercury, the amalgam instantly solidifies and becomes hard; at the same time so much heat is liberated that incandescence is apparent at the point where the metals come in contact, and any combustible fluid, such as naphtha, may be set on fire. Liquefaction produces cold; congelation or solidification, heat.

If liquefaction is pressed further by the addition of more heat, the water is converted into vapour, the molecules are thrust wider apart, and "actual heat" disappears.

This is demonstrated very conclusively in the distillation of water. The heat is applied to the bottom of the vessel containing the water, and when it has once reached the boiling-point, 212°, the steam—the vapour (also at 212°) carries off all the heat of the burning coals; the heat disappears; the thermometer, inserted in the still, remains stationery. When the steam is passed through the condensing apparatus—the coil of pipe, called the worm, surrounded by cold water, and contained in what is called the worm-tub—the heat or energy which it carries off from the fire becomes apparent; the stored heat is so large in quantity that it soon raises the temperature of the water in the worm-tub, and the quantity of water in the tub, which may be raised to 212° F., is much larger than the water condensed. The stored "heat" (already so often spoken of as "potential heat") in the steam becomes "actual" energy when the vapour passes to the liquid condition of matter; and this heat, as already described, is so great, that it may be conveniently applied in the warming of buildings.

The conversion of water into vapour by the method already described is progressive, and unattended with danger. If the water could be suddenly converted into steam, and the specific heat of steam was not so high, the attempt to boil water must always end disastrously, because it would be generated suddenly and explosively; the steady "ebullition," or escape of bubbles of steam, as the cohesion of the molecules is gradually overcome, would not be maintained. The escape of air from water, heated to 212° F., is very apparent when it is boiled in a flask. Tyndall says the air acts as a kind of elastic spring, pushing the atoms of the water apart, and thus helping them to take a gaseous form.

The cohesion of the particles of water appears to be greatly increased when the foreign matter—viz., atmospheric air—is removed. Thus, water allowed to fall through a tube from which the air has been ejected by boiling the water, and melting the glass and hermetically sealing the end, falls collectively, making a noise, and would break through the end of the glass tube like a solid substance. The vacuum-tube containing the water is called "the water-hammer," and if altered in shape by bending it into a V-shaped figure, nicely rounded off at the bend, some very amusing illustrations of the modification of the cohesion of the water and adhesion to the glass can be displayed.

The mechanical nature of the interior of a vessel in which steady "ebullition" is to be maintained greatly affects the escape of the vapour or steam. If the interior surface is too smooth, like that of a flask, and distilled water boiled therein, the flask is said to bump, *i.e.*, the temperature of the boiling water rises a degree or so above the boiling-point, and every time steam is formed it escapes with a sudden jerk, as if it were a slight explosion, and the temperature falls to 212°, again rising and falling with each rush of vapour. When this occurs, it may be instantly corrected by dropping in any metallic filings, zinc or copper, or by placing in the flask a bit of crumpled platinum-foil. The rough edges break up the continuity of the smooth surface of the glass, and serve to conduct the heat of the lamp into the particles of the water, and thus to hasten the disruption of their cohesive power. It is easy to follow out the idea further by lining a copper vessel with shellac. Water placed in a vessel prepared in this manner will not boil until it attains a temperature of 219° F., *i.e.*, seven degrees above the ordinary boiling-point. Bursts of steam occur, the temperature falling after each escape of vapour to 212°. The

hard copper is not in direct communication with the water; there is an intermediate non-metallic body which adheres to it and becomes soft. It is this intermediate physical condition, neither solid nor fluid, but partaking of the physical nature of both, which interferes with the energy of heat, and assists to maintain the cohesion of the water.

Monsieur Donny, of Ghent, has studied this subject very carefully, and has shown that the presence of air is of great importance in maintaining steady ebullition and escape of vapour from water; the tiny volumes of air expand by heat, and into these bubbles the steam passes, expands, and rises.

All spring and river water contains air in solution, and, as steam-boilers are constantly fed with fresh water, the supply of bubbles of air goes on continually.

That the presence of air in solution does assist the escape of the steam is proved by the explosive nature conferred on water after it has been boiled for a lengthened period, so as to get rid of and drive off the dissolved air.

Under these circumstances the temperature of the water rises to 360° F., or 148° above the boiling-point; and such was the violence with which the steam escaped, that an *open* glass vessel was shattered with a loud report.

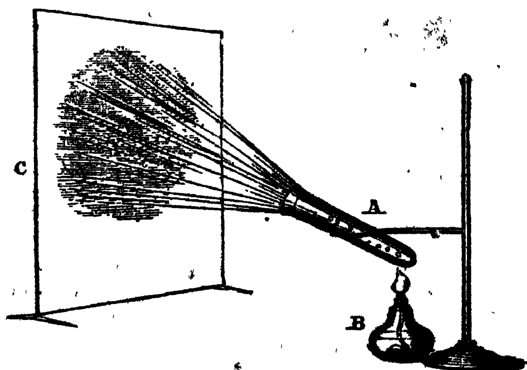


FIG. 166.—*Faraday's Experiment—Boiling Water deprived of Air under Oil of Turpentine.*

A, the tube containing the oil and ice; B, the spirit-lamp; C, the screen of blotting-paper to receive the water and oil when ejected explosively.

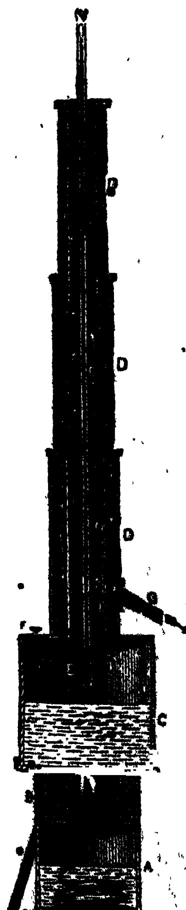
In great manufactories, boilers "banked up," and kept gently boiling from Saturday night to Monday morning by a slow expenditure of fuel, have exploded without warning, and without the engineer having the slightest conception of any dangerous accumulation or pressure of steam. Amongst the precautions taken to prevent accidents is one suggested by the recollection of this property of water; and means should be taken to allow a small quantity of fresh cold water to pass continually into all boilers during the intervals of rest, and especially into locomotives which are sometimes kept "banked up" and ready for service.

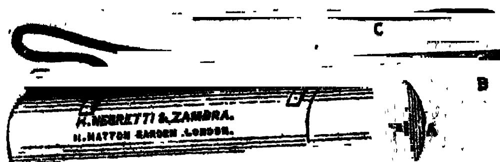
When water freezes, the air, by the compression of the particles, is squeezed out, and none remains in solution. If a piece of Wenham or clear Norwegian

ice is placed in a tube and surrounded with oil of turpentine, and then carefully melted and heated, the boiling-point is raised very high, and, directly steam is generated, the whole contents of the tube are ejected. This experiment was first shown by Faraday at the Royal Institution. (Fig. 166.)

On the principle that the more we increase cohesive force, the greater must be the power of resisting the energy of heat, is explained the rise in the boiling-point of saline solutions. A saturated solution of nitrate of soda boils at a temperature of 249·5° F.; the quantity of salt being 224·8 parts in 100 of water, or more than double the weight of the solvent. Faraday and Magnus have both shown that the steam arising from the boiling saline solution, although escaping at a temperature of 249·5° F., speedily and almost instantaneously adjusts itself to the atmospheric pressure indicating only the ordinary temperature of steam—212° F. When it is said that water boils at 212° at the ordinary pressure, it is meant that the energy of heat, represented by the steam, cannot exert itself, cannot even help the vapour to escape, until it has overcome the pressure of the air, or weight equal to fifteen pounds upon the square inch. The lifting power or energy of heat is well illustrated by this simple fact; and directly the pressure is partly removed, the amount of energy, or heat, represented by the boiling-point is reduced, and the water will enter into ebullition at a lower temperature. The pressure of the air is represented by the height at which a column of mercury is supported: when the mercury is 16·6 inches high, water boils at 184° F.; if the pressure is doubled, and the barometer, the column of mercury, stands at 32·3 inches, water boils at 216° F. The difference between 16·6 inches and 32·3 inches is very great, and it might be thought that such a fall in the barometer could only be demonstrated by artificial means, and by the creation of a partial vacuum with an air-pump. But it must be remembered that there are certain spots on the surface of the globe where the adventurous traveller may ascend nearly three miles above the level of the sea.

The famous De Saussure ascended to the summit of Mont Blanc, which is 15,650 feet above the level of the sea, and where water boils at a temperature of 185·8° F.,





FIGS. 167 and 168.—*Apparatus for determining Elevations by the Temperature of the Boiling-point of Water.*

and the barometer stands at about 17 inches. The boiling-point of water is lowered about one degree for every 590 feet. Dr. Saussure's observations were verified by Tyndall in August, 1859, when the temperature of boiling water at the summit of Mont Blanc was found to be 184·95° F.

It is by the careful observation of the temperature at which water boils that the height of any hill or mountain may be determined. Since Dr Wollaston constructed his instrument for measuring heights by the observation of the boiling-point, improvements have been made, as shown in Fig. 167.

The Barometrical Thermometer, or Hypsometrical Apparatus, as constructed by Negretti and Zambra, is intended to meet the requirements of travellers in circumstances where the mercurial barometer cannot be conveniently employed. The instrument is very portable, and affords a ready and accurate means of measuring heights by observation of the temperature of boiling water. The apparatus is shown in Fig. 167. It consists,

First, of a very delicate thermometer, about 12 in. long, the scale ranging from 180° to 212°, having each degree subdivided, so as to show distinctly 0°·1.

Secondly, a copper boiler, C, attached to a small tripod stand. From the boiler proceeds three double tubes, E E E and D D D, open at top; screwed on the top of the boiler; the outer tube has two openings, one at the top, through which the thermometer E E is inserted, passing down to within an inch of the water in the boiler, and supported by means of an india-rubber washer, as shown in Fig. 167, the second opening forming an outlet for the steam, as shown at G. The object of the double tube is to insure a steady boiling-point, which it would be impossible to obtain in open-air experiments, were only a single tube employed. A is a metallic spirit-lamp, surrounded with wire gauze, B, to prevent the flame being extinguished when experimenting in the open air. The whole instrument, when packed for travelling, is shown, drawn to a smaller scale, in Fig. 168. Each instrument is furnished with a carefully computed set of tables, from which may be obtained, by an easy calculation, the elevation corresponding to any observed boiling-point between the temperatures of 180° and 212°.

To use the boiling-point apparatus, it is simply necessary to pour into the boiler, through the small opening F, on its surface, a sufficient quantity of water to fill it about one-third, and afterwards close it by means of the screw for that purpose; the lighted spirit-lamp is then applied, and when the water is made to boil, the steam rises, surrounding the bulb and tube, and, descending between the two tubes, issues from the opening at G. After a few seconds, the mercury in the thermometer will rise and become stationary; the degree indicated by it must then be noted, when, by reference to the tables, the elevation of the spot where the experiment has been performed may be obtained.

STEAM.

If water boils at a lower temperature when the ordinary pressure of the air is reduced, it should, of course, indicate a higher temperature when the pressure is increased.

Steam, escaping from an open vessel, is usually at a temperature of 212°; but it must always be remembered that the barometer shows that the pressure of the air is constantly varying, and, even within the limits of the range of the

barometrical indications in our climate, the boiling-point of water may vary nearly five degrees.

The temperature of steam is always the same as that of the water from which it is evolved. Consequently, if water is confined in a closed and strong vessel, the temperature of the water may be raised as high as the strength of the vessel will permit.

Marcet's boiler is a very useful and safe piece of apparatus for demonstrating the rise of the temperature of the steam as the pressure is increased. When the water has been poured into the boiler, and the heat of the spirit-lamp applied, it soon boils; and, if the stop-cock remains open, the temperature is shown to be 212° F., and, of course, no mercury rises in the barometer tube. If, however, the stop-cock is closed, the rise of the mercury in the barometer is simultaneously accompanied with an elevation of temperature, indicated by the thermometer; and when the mercury rises to thirty inches, it demonstrates that the pressure is doubled, and amounts to thirty pounds upon the square inch, because there is not only the pressure of the air, but the weight of the mercury to be overcome, before the latter can be pushed up the *open* tube; and looking at the thermometer, it will now be found to stand at 250·5° F.

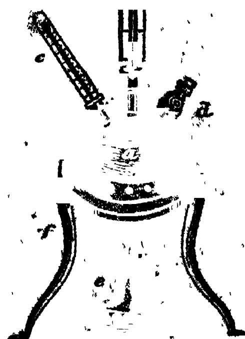


FIG. 169.

The question of the exact pressure which accompanies a rise of temperature in the boiling-point of water, and simultaneously of the steam escaping from it, was very properly made the subject of careful scientific inquiry by the Academy of Sciences at Paris, many years ago, by MM. Dulong and Arago. They obtained facts by experiment up to 25 atmospheres, and from the data so obtained calculated the temperature and pressure up to fifty atmospheres, or 50 × 15 = 750 pounds upon the square inch; giving, by calculation, a temperature of 510·4° F.

A, a strong brass globe, made of two hemispheres screwed together with flanges, and supported on a tripod stand; B, the barometer tube passing through a steam-tight collar, and touching the bottom of the boiler, in which sufficient mercury to fill the tube and cover the end of the barometer tube is placed; C, the thermometer graduated to 400° F., and passing, like the barometer tube, through a steam-tight collar. D is the stop-cock; E, a spirit-lamp.

FORCE AND TEMPERATURE OF STEAM.

Atmosphere.	Temperature.	Atmosphere.	Temperature.
1	212·00° F.	9	350·78° F.
2	250·52	10	358·88
3	275·18	11	366·85
4	293·72	12	374·00
5	307·50	13	380·66
6	320·36	14	386·94
7	331·70	15	392·86
8	341·78	16	398·48

Atmosphere.	Temperature.	Atmosphere.	Temperature.
17	403·82° F.	22	427·28° F.
18	408·92	23	431·42
19	413·78	24	435·56
20	418·46	25	439·34
21	422·96		

The above temperatures and pressures apply only to steam in contact with water. "Dry steam" is affected by heat precisely in the same manner as the permanent gases.

The energy called heat is, as we have seen in the remarkable experiment of Groves, capable of application until a body is decomposed into its elements (see p. 152, "The Decomposition of Steam by Heat into Oxygen and Hydrogen"). It is not then surprising that the instrument called Papin's digester should exert such a powerful solvent action upon matter subjected to the high temperature of steam produced by confining and heating water in a very strong vessel.

In using an ordinary still for obtaining distilled water, supposing one gallon of distilled water to be obtained, and the steam representing that measure of water to have been passed into five gallons and a half of ice-water—viz., water at a temperature of 32° F.,—the energy or heat carried up from the fire, and converted for a brief space, in passing from the still to the worm, into potential or stored force, is so great that it will raise the 5½ gallons of water at 32° to 212° F. when condensed or converted into actual energy or heat. The elasticity of the molecules of water must be enormous, to permit the vibratory power or energy called heat to separate them so widely apart. By the same amount that they are separated, so they must return. The act of unlocking, or conversion into steam, is followed by condensation—the locking of the molecules, and the production from that motion of an enormous amount of heat, usually spoken of as "latent heat"—a term that may be usefully retained so long as the cause, "motion," is not lost sight of. The "latent heat" of vapour is a question of considerable importance. The illustrious Watt observed by experiment that the *same weight* of steam, whether it escapes at 212° or 300° F., exhibits very nearly the same amount of heating power or latent heat; and although Regnault, by more elaborate experiments, has determined "that the total quantity of heat necessary for the evaporation of water increases with the temperature," it is found in practice that Watt's conclusion, that the latent heat of steam is increased in the proportion that the "sensible heat" is absorbed, is sufficiently correct for ordinary working purposes.

A given weight of steam at 212°, condensed at 32° F., evolves	180° sensible heat,
	950° latent heat.
	1130
The same weight of steam at 250° . . .	218° sensible heat,
	912° latent heat.
	1130

The same weight of steam at 100°	68° sensible heat,
	1062° latent heat.
	1130

Regnault's experiments show that the total quantity of heat necessary to evaporate water at 100° C. (212 F.) is equal to 637; at 120° C., it is 643; at 150° C., it is 651. These conclusions are at variance with those arrived at by Watt, but, as already stated, are too minute to affect the main question.

To work out the figures representing the latent heat of steam, a simple arrangement of apparatus may suffice.

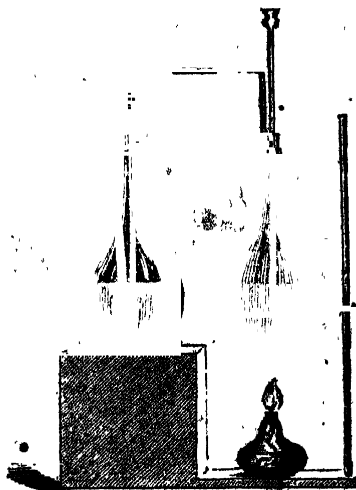


FIG. 170.—*Flasks arranged to show the Latent Heat of Steam.*

Thus, supposing each flask to contain eight ounces of water at 60° F., and the steam from one of them be conducted into the other until the temperature is raised to 188° F., or increased 128°, it will be found that one flask has lost one ounce of water, which the other has gained.

The whole heat carried over with the one ounce of steam into the eight ounces of water will, therefore, be $128° \times 8 = 1024°$.

But the 1024° cannot be all regarded as latent heat, because the steam, whilst condensing, should have raised the water to 212° F.; therefore, 188° F. must be deducted from 212° F., which will leave 24°; and now $1024° - 24° = 1000°$, the latent heat of steam.

When the steam is allowed to escape from the Marcet boiler (p. 173) at a pressure of two atmospheres, and at a temperature of 250·5° F., it would be imagined that the steam must severely scald the hand if held in the jet whilst escaping under these circumstances. Curious to say, this is not the case: the steam, as it escapes, is comparatively cool, and the hand may be held in it with perfect impunity.

Here expansion takes place; the particles of the vapour of the water are closely packed and squeezed together; the steam, whilst inside the boiler, is of greater density; the heat apparent is "actual force," but directly it escapes work is consumed in the return of the vapour to its normal state of pressure, and thus the heat becomes "potential," or is rendered latent or insensible.

Any gas or vapour in the act of expanding, that performs work, consumes heat.

If air is compressed in a strong cylinder and allowed to escape, the elastic force which pushes out the air represents work; and as heat is consumed, the stream of air is found to be cold. When air is forced out of the nozzle of a common pair of bellows, the air is slightly warmer than the external air, because it is the *human muscles* that do the work: it is the stoppage of the motion of the air from the bellows that produces the slight increase of heat. It was not the elastic force of the air behind the escaping portion (as with the compressed air in the iron vessel) that caused the air to escape from the bellows; it was human strength, and if that had not been sufficient no air would have escaped: a baby cannot work a pair of bellows. It was formerly taken for granted that in every case where gases and vapours expand cold must be produced; but Gay-Lussac and J. P. Joule have clearly proved that you may have expansion without producing cold, provided no work is performed.

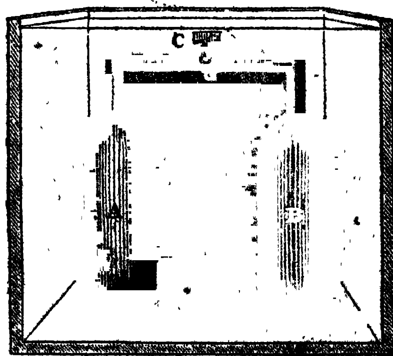


FIG. 171.—*Gay-Lussac's Experiment.*

A, B, two copper cylinders; C, the connecting-pipe and stop-cock.

This experiment proves very beautifully that where no work is performed there is no cold; and in this experiment gas is allowed to expand without doing work.

The vessel A is first exhausted, and the other, B, left full of air; when the cock is turned, the air rushes out of B into A. The air which fo[illegible] filled B is now divided between B and A, and, if pumped back, would [illegible] B. The half, in expanding from B into A, has performed work, and co[illegible] heat. It is cold; but, striking against the interior of the copper vesse[illegible] stopped, and heat is generated. The heat produced in A by the arrest of motion is exactly equivalent to the loss sustained in B by work, by the exertion of the elastic force; hence the two effects of cold and heat neutralize each other, and

the temperature of the air in the two vessels, when thoroughly mixed, remains unaltered. There is no work performed, and no heat lost.

A still more satisfactory experiment was performed by J. P. Joule. He compressed air with a force equal to twenty-two atmospheres into a metallic vessel —he had twenty-two atmospheres squeezed into a space usually containing one only; he pumped the air out of a similar metallic vessel, producing a vacuum. The vessels were connected, like Gay-Lussac's, with a tube and stop-cock, and surrounded with water. On turning the cock, the air expanded from one vessel into the other, and, by keeping the water surrounding both vessels properly stirred, no increase or decrease of heat was observed in the water. The — heat or cold in one vessel exactly balanced the + heat in the other, reminding one of plus or positive and minus or negative electricity, which exactly neutralize one another. These experiments are very satisfactory, and support greatly the dynamical theory of heat.

Professor Rankine, in his valuable "Manual of the Steam-engine," examines the question, whether latent heat be a materiality or not, very clearly. He says,

"The term '*latent heat*,' when freed from hypothetical notions, means an amount of that condition of matter called *heat* which has disappeared in producing physical effects different from heat—such as expansion, fusion, evaporation, and chemical changes—and which may be made to reappear by reversing the changes in which such physical effects consisted; that is, by compression, congelation, liquefaction of vapours, and inverse chemical changes. The progress in the true theory of thermo-dynamics, to which this discovery might have led, was for a long time retarded by a fallacious principle, arising from the hypothesis of substantial caloric, in the following manner:—Let a substance change from a less bulky to a more bulky condition, or from the liquid to the gaseous state, or generally from the state A to the state B, that change being of such a nature that, according to Black's discovery, heat disappears, and some physical effect different from heat is produced.

"Let this operation be called A B, and let H_1 be the amount of heat which disappears.

"Next, let the substance change back from the state B to the original state A: let this change be called B A. It will cause a certain quantity of heat, H_0, to reappear. If the series of intermediate changes undergone by the substance during the process B A be exactly the reverse, step by step, with those undergone during the process A B, everything done by the first process will be exactly undone by the second: no permanent physical effect will ensue from the combined processes; and the amount of heat which reappears, H_0, must necessarily be equal to the amount of heat, H_1, which formerly disappeared. This was understood from the time of the first discovery of latent heat; and so far there is no fallacy, but an important truth. But it was further assumed that heat has a *substantial existence*, and that, consequently, $H_0 = H_1$ under all circumstances, even although the processes, A B and B A, should differ in their intermediate steps. This assumption leads to the following paradoxical result, which shows it to be fallacious:—It is known that the process B A may be made to differ from A B in its intermediate steps in such a manner that a permanent mechanical effect shall be produced by the combined processes. Now, if under such circumstances H_0 is assumed to be still $= H_1$, it follows that, by employing the mechanical effect of the combined processes in *developing heat by friction*, we may *increase the amount of heat in the universe*, or *create caloric*—a consequence opposed to the

original assumption of the substantiality of caloric, and proving that assumption to be self-contradictory."

Further on, Professor Rankine, speaking of the hypothesis of molecular vortices, remarks that, "In thermo-dynamics, as well as in other branches of molecular physics, the laws of phenomena have, to a certain extent, been anticipated, and their investigation facilitated by the aid of hypotheses as to occult molecular structures and motions with which such phenomena are assumed to be connected.

"The hypothesis which has answered that purpose in the case of thermodynamics is called that of 'molecular vortices,' or otherwise the 'centrifugal theory of elasticity.' On this subject, see the 'Edinburgh Philosophic Journal,' 1849; 'Edinburgh Transactions,' vol. xx., and 'Philosophical Magazine,' *passim*, especially for December, 1851, and November and December, 1855—'Science of Energetics.' Although the mechanical hypothesis just mentioned may be useful and interesting as a means of anticipating laws, and connecting the science of thermo-dynamics with that of ordinary mechanics, still it is to be remembered that the science of thermo-dynamics is by no means dependent for its certainty on that or any other hypothesis, having been now reduced to a system of principles and general facts, expressing chiefly the results of experiments as to the relation between heat and motive power.

"In this point of view, the laws of thermo-dynamics may be regarded as particular cases of more general laws applicable to all such states as constitute '*energy*,' or the capacity to perform *work;* while more general laws form the basis of the 'science of energetics'—a science comprehending, as special branches, the theories of motion, heat, light, electricity, and all other physical phenomena."

A cubic inch of water, converted into steam under the ordinary pressure of the atmosphere, expands into 1696 cubic inches, or nearly one cubic foot.

It is the change of water into vapour, converted in its turn into mechanical motion, which constitutes "energy," or heat, the first of "prime movers," and now bringing us to the Steam Engine.



Heathfield Bown. Jany 13 1816

Yours obliged hum

James Watt

FIG. 172.—*Portrait of Watt, after Sir W. Beachy, and Watt's Autograph.*

ON THE STEAM ENGINE.

The limits of this work will not permit of any lengthened description of the various ingenious extensions, modifications, and improvements of the original and successful steam engine of Watt—invented and constructed by him between 1759 and 1784. Omitting the history of the steam engine before the period of 1759, which the reader will find fully described in the works of Tredgold, Farey, Lardner, Bourne, and others, we find, according to the "Memorials" of Watt, carefully collected and published by Mr. George Williamson, late Perpetual President of the "Watt Club," of Greenock, that "it is in the little town of Crawfordsdyke, about the middle of the seventeenth century—a small burgh in the parish of Greenock, and closely adjoining the town of this name—that we first meet with the name of Thomas Watt.

"At what period of his life he settled here cannot now be known.

"His object, no doubt, was to establish himself in some locality where those branches of scientific knowledge connected with the mathematics, such as astronomy and navigation, might be rendered available as a profession. This Thomas Watt was the grandfather of the great mechanician, and he was born during the civil wars between Charles I. and the Parliament; the exact date of his birth appears to be doubtful, but it must have been between 1639 and 1642. After coming to Crawfordsdyke, he became a teacher of the mathematics and the principles of navigation; and on his tombstone (for he died on the 27th February, 1734, aged 95) he is styled 'Professor of the Mathematics.'

"Thomas had two sons, the elder John and the younger James Watt; the latter, a merchant of Greenock, the father of the great engineer, was raised to office of bailie or magistrate of Greenock in the year 1757. He died in 1782, at a good old age, having attained to his eighty-fifth year. The flat tombstone, placed by his illustrious son, James Watt, records the deaths of his father, mother, and brother, John Watt; and the inscription ends with these words:

'TO HIS REVERED PARENTS,
AND TO HIS BROTHER, JAMES WATT
HAS PLACED THIS MEMORIAL.'

"Of the mother of Watt it was said by another lady, who knew her, that she was '*a braw, braw woman; none now to be seen like her.*'

"From her he received his first lessons in knowledge; and although, by their very gentleness, he may have been rendered doubly sensitive under the ruder and more popular methods of the public school to which he was afterwards sent, there is every reason to believe that the very aversion occasioned in his mind to the rough sports and hard usage of his less exquisitely refined playmates conspired with other causes to further rather than impede the steady development of his future powers. The truth in regard to young Watt's first years in the public school is, that, owing doubtless to infirm health, the suffering and depression which affected his whole powers, he was unfitted for a considerable time for displaying even a very ordinary and moderate aptitude for the common routine of school-lessons, and that during these years he was regarded by his schoolmates as *slow* and *inapt*.

"At thirteen years of age young Watt, like that other giant of Timnath when the Philistines were upon him, *woke up* into something of his real strength on being put to the study of the mathematics.

"This the author observes to be the true date of his *intellectual* birth—the happy moment when he took into his hands the mystic key of all scientific knowledge, with which in after-years he was successively to unlock so many of the secrets of nature, and lead mankind to the participation of some of her most precious treasures."

We pass on through the philosopher's boyhood, his sober pastimes, and his cultivation of the learning of a sage, mathematics and astronomy, until we arrive at his first studies in the practical mechanics—"the making and fashioning of such miniature pulleys or blocks, pumps and capstans, with their levers or bars." These objects were all in course of manufacture on his father's premises, who was not only a merchant, but a "master-wright," and made such carpentry as the outfit and supply of the shipping demanded—gun-carriages, blocks, pumps, capstans, *dead-eyes*, figure-heads, and the first "crane" at Greenock, for the convenience of "the Virginian tobacco-ships" then frequenting the harbour.

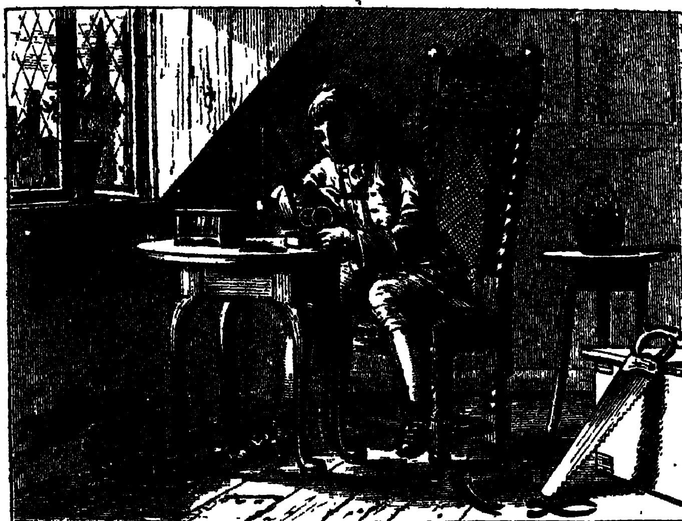


FIG. 173.—*Boyhood of Watt.*

"A scene of useful labour such as this was a fitting school for the genius of him who afterwards was to become the leading mechanician of the day.

"In clearing out an attic room used by Watt when a youth in his twelfth or thirteenth year, it is stated by a late master-shipwright of Greenock that he found a quantity of ingenious models, and among these models he remembered in particular a miniature *crane* and a *barrel-organ*. Watt is known subsequently to have constructed several musical instruments, particularly an organ of some dimensions and power, while he was in Glasgow, which, it is said, produced the most remarkable harmonious effects, so as to delight even professional musicians; the more remarkable because it is added that he could not distinguish one note from another, and was wholly insensible to the charms of music.

"Having completed his attendance at the grammar-school, young Watt was for a year or more industriously occupied about his father's premises, either as an amateur or in the way of intentionally acquiring an accurate knowledge of the various nautical and scientific instruments left with his father for adjustment. At all events, he had a small forge erected for his particular use. It is probably to this period that his fabrication, for one of his friends, of a *punch-ladle* out of a large silver coin is to be referred.

"In the year 1753, and after the death of his mother and the altered circumstances of his father, at the age of seventeen or eighteen, he was sent to Glasgow to reside with his maternal relations; and in the year 1755 went to London with the view of perfecting himself in the profession which it would appear the inclination of the time, as well as the circumstances in which he had been brought up, dictated as the most expedient.

"Ill health compelled him to leave London, and he returned to Greenock in

1756, and in the course of this year probably settled in Glasgow for the prosecution of his business as a mathematical-instrument maker.

"Watt arrived in Glasgow in his twenty-first year; but the Corporations of Arts and Trades, the Corporation of Hammermen, grounding upon their ancient privileges, looked upon the young artist from London as an intruder, and obstinately denied to him the right to open even the most humble workshop. Every means of conciliation having failed, the Institution of Glasgow interfered, arranged and put at the disposal of the young Watt a small apartment within its own buildings, allowed him to establish a shop, and honoured him with the title of its instrument maker. Here the young mechanician made the acquaintance, and then acquired the sincere friendship, of a most distinguished and benevolent man, the founder of the Andersonian Institution of Glasgow, who, in addition to the labours of his own class, which were strictly academic and philosophical, instituted a class and lectures for *workmen*, and for those whose pursuits did not allow of their conforming to the prescribed routine of university studies; to which *anti-toga* class, as he designated it, he continued throughout a long life, terminated only at the advanced age of seventy, to lecture twice every week during the session of college.

"Such a man, one would say, was eminently *he* under whose inspiriting influence it were to be desired that the adventurer in the philosophical instrument business should have fallen. It was Professor Anderson who put into the hands of Watt the famous model of Newcomen's engine, which belonged to the apparatus of the professor's class, and wanted repairing.

"In his little university room Watt now speculated and experimented; his workshop became the resort of learned professors, as well as students—'a kind of academy,' says Arago, 'whither all the notabilities of Glasgow repaired to discuss the nicest questions in art, science, and literature.' It was here, as stated in the note appended to the model of the Newcomen engine in the Hunterian Museum of Glasgow, that 'in 1765 James Watt, in working to repair this model, belonging to the Natural Philosophy Class in the University of Glasgow, made the discovery of a *separate condenser*, which has identified his name with that of the steam-engine.'"

Watt had accomplished his grand discovery, the "separate condenser," and now formally registered his patent for "A Method of lessening the Consumption of Steam, and consequently of Fuel, in Fire Engines."

He enrolled in Chancery his threefold specification of an effective, workable steam engine, a high-pressure engine and a horizontal rotatory engine. *Money* (*!!*) only now was wanting to give to his country and the world the boon for which science and labour were alike waiting. This was not denied to genius in this case, because industry was not wanting. The young workman falls in with Smeaton; their histories were similar; and now the young mathematical-instrument maker becomes a surveyor and civil engineer. Mr. Watt was next employed in the experiments and improvements going forward at the Carron Iron Works, under the famous Dr. Roebuck, who first defrayed the expense of carrying out Watt's invention.

For a series of years prior to the failure of Dr. Roebuck's magnificent undertakings, and Mr. Watt's consequent settlement, with the famous Matthew Boulton, at Soho, near Birmingham, about 1774-5, his principal professional occupations were those connected with the business of civil engineering, or surveying, as it then continued to be called. He was employed in 1769 to survey the River Clyde. "We see, in fact," remarks Arago, "the creator of an

engine destined to form an epoch in the annals of the world undergoing, without murmur, the undiscerning neglect of capitalists—during eight years turning the lofty power of his genius to the getting up of plans, to paltry levellings, to wearisome calculations of excavations and embankments and courses of masonry."

Time, however, works wonders. Watt is now invited to join Mr. Boulton, of Birmingham, who had taken Dr. Roebuck's place, and received from him the most generous and hearty assistance in the further prosecution of the manufacture of the steam engine. It was the energy of Boulton which rendered the genius of Watt practically available; and Watt, in his "Notes on the Steam Engine," says—

"As a memorial due to that friendship, I avail myself of this, probably a last, public opportunity of stating, that to his friendly encouragement, to his partiality for scientific improvements, and his ready application of them to the processes of art, to his intimate knowledge of business and manufactures, and to his extended views and liberal spirit of enterprise, must, in a great measure, be ascribed whatever *success* may have attended my exertions."

Watt, at the period of his leaving Scotland, was about thirty-eight or thirty-nine years of age; and "had Watt," says Playfair, "searched all Europe, he could not have found another man so calculated to introduce the invention to the public in a manner worthy of its importance."

Watt, by the advice of Boulton, applied to Parliament for an extension of his patent. £50,000 had already been expended in the manufacture of engines and defence of the patent by Boulton and Watt before any return was realised.

The extension was granted for a term of twenty-five years, dating from 1775. This important concession being secured, Boulton and Watt invited the utmost publicity. Mechanics and scientific men crowded to see the capabilities of the new machines. The Cornish and other miners, and all employers of power, were shown the working and economy of the new system. The patentees themselves said, in their prospectus, "All that we ask from those who choose to have our engines is *the value of one-third part* of the coals which are *saved* by using our improved machines, instead of the old. With our engines it will not, in fact, cost you but a trifle more than half the money you now pay to do the same work, even with one-third part included, besides an immense saving of room, water, and expense of repairs.

"The machine itself which we supply is rated at that price which would be charged by any *neutral manufacturer* of a similar article. And, to save all misunderstanding, to engines of certain sizes certain prices are affixed."

The dates of Watt's inventions are as follows:

1769. The first patent involving the saving of steam and fuel—the invention of the "cutting off of steam," to enable it to work expansively.

1776. The invention of the "double-acting steam engine," and the application of the crank to it; also the adaptation of this engine to the production of rotatory motion.

1784. Other patents of invention, viz., the parallel motion, the counter which registered the strokes of the engine, the governor, the throttle valve, the indicator for ascertaining the power of an engine, and a locomotive engine, the latter never practically tested. By the time this work is printed and circulated, a hundred years will have elapsed since Watt took out his first patent.

How many patents for steam engines have been taken out during that period it would be hard to say. Every requirement which steam power can fulfil is

now satisfied; and, classing the various forms with reference to their purposes, we find, according to Rankin, the following classification:

"I. Stationary engines, such as those used for pumping water, for driving manufacturing machinery, &c.

"II. Portable engines, which can be removed from place to place, but are stationary when at work.

"III. Marine engines, for propelling vessels.

"IV. Locomotive engines, for propelling vehicles on land."

After the time granted to Watt by Parliament had expired, he retired from the firm, leaving his son and his partner's son to continue in the same path of honourable industry.

The patent expired in 1800; and Watt died in the house which he occupied at Heathfield during his sojourn at Soho, on the 23rd of August, 1819. He lies buried in the parish church of Heathfield, at Handsworth, where a Gothic chapel, containing a marble statue by Chantrey, was erected to his memory.

The next figure (Fig. 174), taken from Walker's "System of Familiar Philosophy," published in 1801, will give the reader a good notion of the construction of one of Watt's single-acting engines, and what was even then called "Boulton and Co.'s new-invented patent fire engine."

A. The boiler, about half filled with water.

B. The steam-pipe, that conveys the steam into the cylinder.

C. The door, where a person may enter to clear out the boiler.

D. The loaded or safety valve; forced open by the steam when too strong, or to be opened by the handle *c*.

E. Feeding-pipe, from the warm-water cistern *s*.

F. Fire-door, opening to the fire under the boiler.

G. The ash-hole.

H. The cylinder, having a piston in it on the end of the rod *d*, which works through the air-tight stuffing-box *o*.

I. Nozzles, where the steam is let out.

K. Plug frame, to open and shut the valves in its rising and falling, thereby suffering the steam to pass to the condensing-pump Q.

L. Beams that support the cylinder.

M. The exhaustion-pipe, that conveys the steam through the cold-water well *o* to the pump Q.

N. Injection-pipe in the cold well, to throw a little cold water into the exhaustion-pipe M.

O. The blowing-pipe, to let out the air that might accumulate in the air-pump Q.

P. The barometer, to compare the strength of the steam with the pressure of the atmosphere.

Q. The air-pump, immersed in a well of cold water. When its piston ascends by the chain, it draws the steam out of the cylinder, and condenses it by the coldness and the vacuum in the pump. The steam becoming water by this means, the piston descends into it, the piston-valve is opened by the water (as in a common pump), and the next ascent of the piston forces that warm water through the box R, up the pipe *r*, into the cistern S (which pipe is cut short in the drawing, but it begins at the box R). This water supplies the boiler.

R. The box of the pipe *r*.

S. The cistern of ditto.

T. A forcing-pump, whose solid piston is forced down by the weights *t*, and

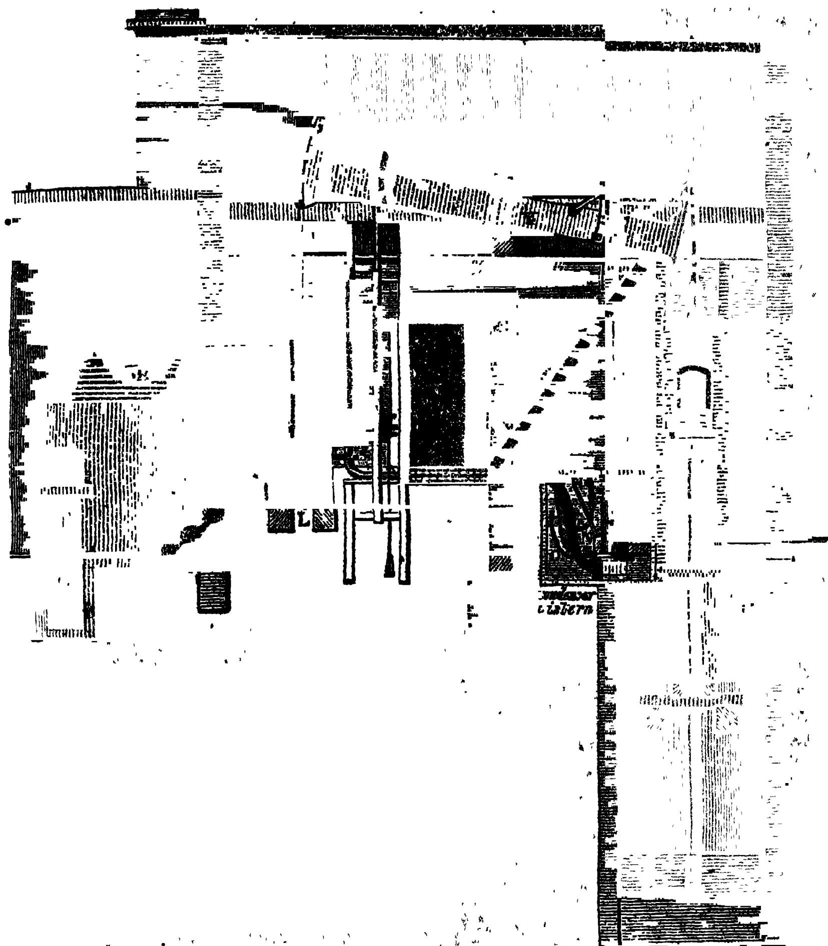


FIG. 174

the piston of the cylinder H drawn up. When the steam from the boiler forces down the piston of H, the piston in T rises, and rarefying the air in the inside or barrel of the pump, the pressure of the atmosphere on the surface of the well forces up the water, as in a common pump; but, by the descent of the piston in T, the water is forced through the pipe X to the place where it is wanted.

W is an air-vessel, to prevent the bursting of the pipes.

Y. The great lever-beam.

Z. The pipe to feed the condenser cistern, O N Q.

The above is Walker's description of one of the first engines made by Watt for pumping water from mines. They are still used for this purpose in Cornwall, and are called "single-acting engines," in which the steam performs its work by its action on one side of the piston only; a counterpoise fixed to the other end of the beam causes the piston to rise.

Walker finishes his description by saying, "that this excellent machine is sometimes made to work by the pressure of steam both upwards and downwards; *i.e.*, the steam can be made to press the piston up, as well as down. This adds considerably to the first expense and the continued expense of fire."

This Cornish engine, made by Watt, is a singular contrast to the engines of the present day, in which the consumption of fuel, and consequently the work performed, is carried to the most refined and absolute degree of perfection. Engines have been made to perform the *duty* of raising one hundred million pounds of water one foot high by the consumption of a single bushel of coals.

The essential portions of the steam engine are better studied in Watt's "Double-action Engine." In this, as in the single-acting engine, the "cylinder" holds the first place.

This consists of a cylinder of metal, A D, provided with a piston, B, the end of which passes through a stuffing-box, C, and is connected with the beam by a beautiful arrangement called the parallel motion (Fig. 177). The steam is passed into this cylinder both *above* and *below* the piston with the utmost regularity, by means of a sliding valve, E. This valve opens a communication between the interior of the boiler and the cylinder, and the condenser and the cylinder, in such a manner that, whilst the steam is using its power on one side of the piston, it is at the same time creating a vacuum on the other side, by passing into a box called the condenser, F—the famous "*separate* condenser" of Watt—to which an air-pump is attached to remove any air that may collect. the condensed water, and also that used for injection.

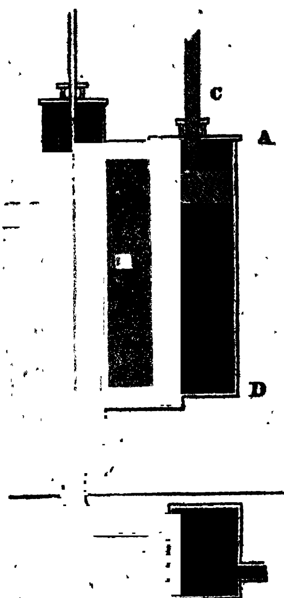


FIG. 175.—*The Cylinder, Valve, and Condenser*

The sliding of the valve upward and downward is effected by means of another admirable mechanical arrangement, called the "eccentric."

In nearly every kind of engine there is attached to the beam and piston-rod a "parallel motion," in order that the piston-rod may always move in a straight line. This simple mechanical arrangement is one of the happiest of the inventions which seem to have come, as it were, intuitively to the well-educated mind of Watt.

To render the working of the double-acting engine as perfect as possible, and to prevent the bad effects of sudden and violent working by excess of steam, Watt caused his engine to regulate its own motion by

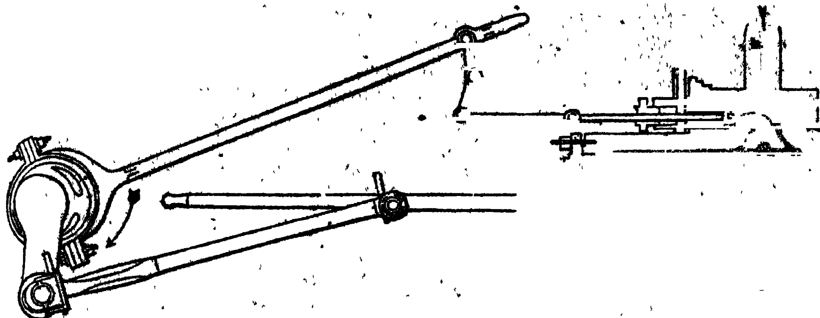


FIG. 176.—*The Eccentric.*

what is called the "governor." This was not wholly the invention of Watt, as the same principle had been previously used in the regulation of sluices of water-mills, under the name of the "lift-tenter;" but the merit due to Watt is

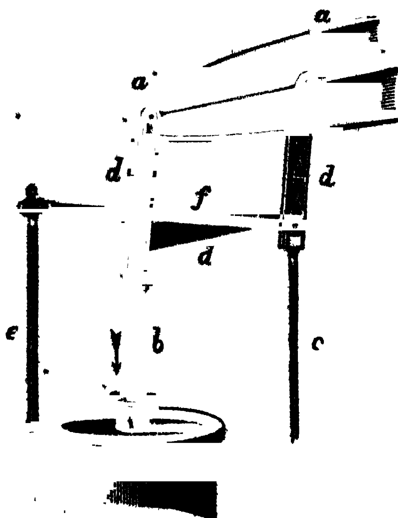


FIG. 177.—*ne Parallel Motion.*

a a, the beam; b, the piston-rod; c, the air-pump rod; d d d, the links; e, rod fixed to the cylinder support the guiding arm or radius rod, f.

y adjusting the contrivance to the opening and shutting of the ... the boiler by a valve called the "throttle valve," so that when the engine is inclined to go fast, and use too much steam, the balls of the governor fly out by centrifugal force, and, acting on the throttle valve, the steam is cut off, and the velocity of the engine reduced.

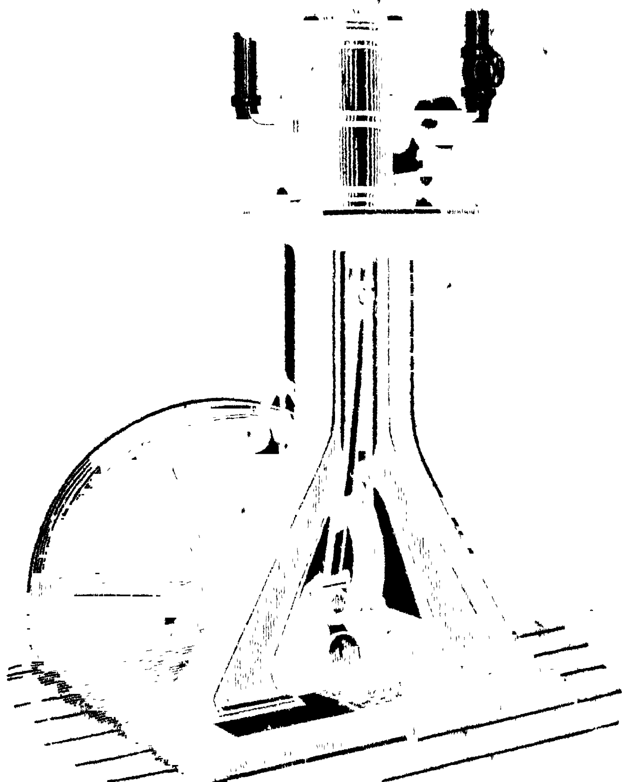


FIG. 178.—*The Governor and Throttle Valve, as used in a 2½ horse-power High-pressure Steam Engine, by Belliss & Seekings, Great Exhibition, 1862.*

The governor in the above engine acts upon an equilibrium or double-beat throttle valve, through the intervention of only a single lever; and the comparative absence of resistance renders its action peculiarly sensitive.

The most important features of the "vacuum" or "condensing engine" Watt having been discussed, the high-pressure steam engine, such as that delineated at Fig. 178, may next be considered. Their form is legion; they may be beam engines or horizontal or vertical engines. The machinery comprised in their construction can be fitted up in a much smaller space; and they differ from the "vacuum or condensing engine" by the absence of those parts which give the name to Watt's engine. The air-pump and condenser are removed, and the steam, after performing its work, is allowed to escape directly into the atmosphere. An illustration of a small engine is given, because the high-pressure principle is well adapted for nearly all small

engines, and it is especially to be noted in the locomotive. Portable engines, which can be removed from place to place, but are stationary when at work, are all worked on the high-pressure principle. At the great French Exhibition of 1867, our manufacturers of portable steam engines for agricultural purposes, such as for working thrashing-machines, ploughing, &c., &c., received many more gold medals than those of other nations; and the excellence of the machinery used by advanced and intelligent farmers in England has created a trade with foreign countries which, in spite of the low wages of the engineers of the Continent, is still most thriving and lucrative.



FIG. 179.—*Howard's Patent Steam Ploughing and Cultivating Apparatus.*

The apparatus delineated in the above engraving includes the engine, the windlass, the wire rope, the cultivator, the anchors, and pulleys. The young people for whom this book is intended have so many opportunities of studying the locomotive engine at the various railway stations, that it is presumed the general outline of this most important class of engines must be sufficiently known to all.

The interior of a locomotive can hardly be thoroughly understood without one of those valuable sectional models made by Messrs. Elliott Brothers, of Charing Cross. The models have sectional working gear, and accurately define the various parts and their respective uses; and all good schools should possess sectional models of the Watt condensing engine and of the locomotive or high-pressure engine.

At the Exhibition of 1862 was exhibited a locomotive engine, built for the London and North-Western Railway Company by Mr. Ramsbottom, their locomotive superintendent, at Crewe, being a good specimen of a first-class passenger engine. It was fitted with patent pistons, duplex safety-valves, and lubricators, and adapted for burning coals with great economy.

An engine of this class ran the American express, on the 7th January, 1862, a distance of 130½ [illegible] *without stopping*, at an average

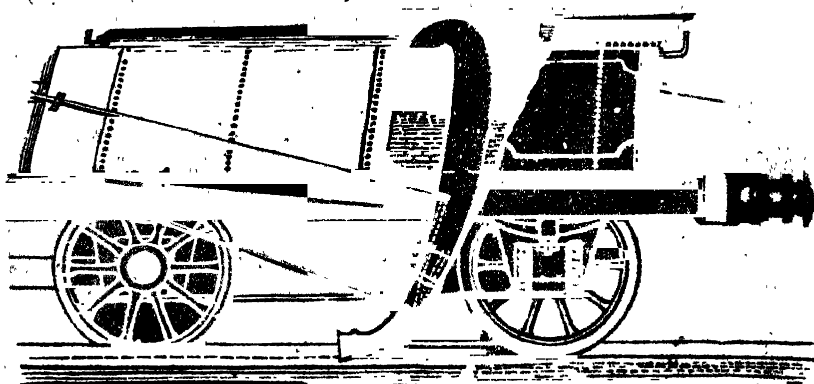


FIG. 180.—*Apparatus for Supplying Water to Tenders whilst in motion.*

miles per hour. The tender attached (Fig. 180) was fitted with Mr. Ramsbottom's most ingenious apparatus for taking up water *whilst running.* The plan has been in daily operation on the Chester and Holyhead Railway since it was first adopted in the winter of 1859-60. By it various quantities of water, from 1,200 gallons downwards, can be picked up, at speeds ranging from 22 miles to 50 miles and upwards per hour. In the running of the Irish mails, the arrangement has the effect of reducing the dead weight of the tender about six tons, equal to the weight of a loaded carriage.

These engines are added to the enormous screw engines manufactured by Messrs. James Watt & Co. The latter consist of four cylinders, each of 84 inches diameter.

The paddle-wheels are driven by four engines, each of 72 inches diameter of cylinder and 14 feet stroke, and rated collectively at 1000 nominal horse-

the Exhibition of 1862 some good examples of high and low pressure marine condensing engines, with surface condensers, were shown by George Rennie & Son.

The advantage of two cylinders in direct-acting marine screw engines is that of working steam expansively, whereby economy of steam and fuel is obtained, depending on the pressure of the steam and the relative volumes of the high and low pressure cylinders. These engines are fitted with surface condensers, with copper tubes and improved centrifugal pumps for circulating the water in the condensers, these pumps being made on a double-curvature principle of least resistance to the flow of water occasioned by the centrifugal force generated by the angular velocity of the pump.

Engines on this principle are fitted with boilers in proportion. Apparatus for superheating steam and feed-water heaters may be made to consume not

1 horse-power.

The important principle of working steam *expansively* has been applied

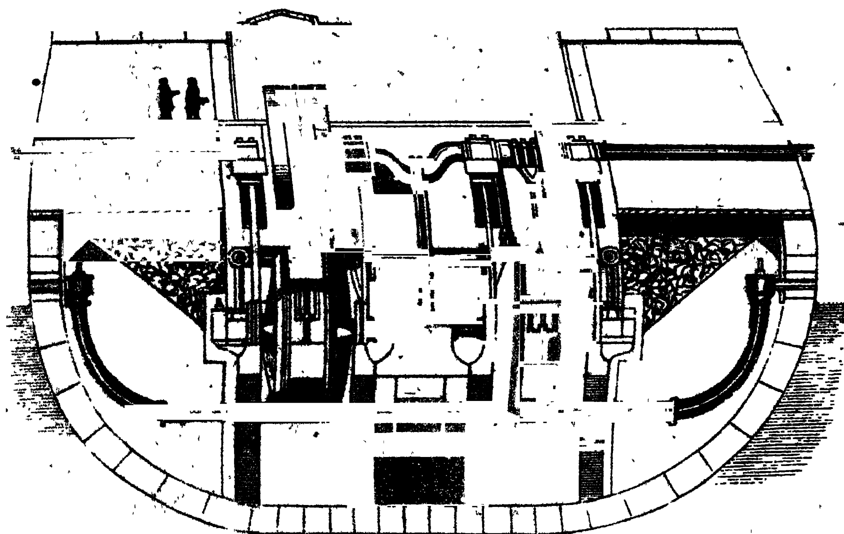


FIG. 181.—*The Paddle-Wheel Engines of the Great Eastern.*

with the greatest success in large engines, made like the Cornish ones, for pumping enormous quantities of water for the use of great cities like London.

Steam of high pressure is used, and when admitted to the piston it is cut off at one-eighth or one-tenth of the stroke. At the Kent Waterworks the Cornish engines used are two with cylinders of 70 inches and 10 feet stroke, two with cylinders of 60 inches, and two smaller ones; in these engines the expansion was not more than one-fifth. The high-pressure, condensing, double-cylinder engines erected at Ditton for the Lambeth Waterworks, and at Kingston for the Chelsea Waterworks Company, can accomplish, according to Mr. Simpson, in ordinary work, 90 million pounds raised 1 foot high per one hundredweight of coals consumed.

The returns of the work performed by the Cornish pumping engines have been given from an early date, and are very interesting.

1769, John Taylor gave the return at only 5½ millions.

In 1800	. .	20 "
" 1815	. .	50 "
" 1835	. .	125 "

The latter 125 millions was at Fowey's Consols Mine, where Austen's engine was used. It might almost be disputed whether such an amount of duty was ever done; but it was well authenticated by the report of the committee appointed, and they reported that the work was done with a bushel of coals weighing 94 pounds.

The principle of expansion was used by Watt, but without any result; but Woolf and Trevithick applied the system with higt steam, and realised the economical results already referred to. With respect to the double-cylinder engine, this was invented by Jonathan Hornblower, and not by Watt. It was patented by the former in 1781. The first and second patents of Hornblower contain the following:

"First, I use two vessels in which the steam is to act, and which in other steam engines are generally called cylinders.

"Secondly, I employ the steam, after it has acted on the first vessel, to operate a second time on the other, by permitting it to expand itself, which I do by connecting the vessels together, and forming proper channels and apertures, whereby the steam shall occasionally go in and out of the same vessel."

The third invention was for "surface condensation," a term already used, and meaning the application of cold water on the other side of a plate forming the side of the box containing the steam. The more perfectly the circulation of the cold water can be maintained, the better is the condensation. A surface-condenser represents the worm attached to a common still, and this invention evades the "separate condenser" in the patent of Watt.

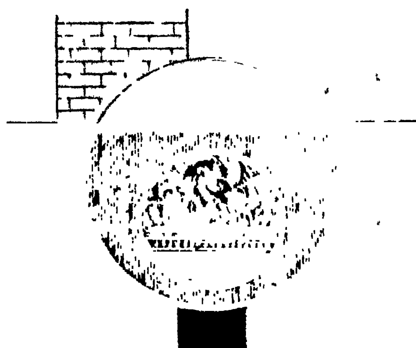


FIG. 182.—*A Cornish Boiler.*

Professional men have discussed the respective merits of the single and double cylinders, and Mr. Hawksley stated, as the result of his experience, "that when raising water from a pit, the Cornish engine (single cylinder) would work well; but it would perform best when pumping out of a deep pit, and when it had a large amount of heavy rods to continue its action and diminish its initial velocity. In the case of *dear* coal he would employ the double cylinder; in the case of *cheap* coal he would [illegible] ngle cylinder; and either not cut off the steam at all, or not much [illegible] the end of the stroke.

With the double cylinder he would use eight expansions; [illegible] little was gained by the system of [illegible] worth carrying it further.

In order to economise coal, and, of course, to [illegible]

of a vessel, the "Combined Vapour Engine" was invented by M. du Trembley. This ingenious arrangement provided that, after the steam had done its work in the cylinder, it passed to the surface-condenser, which was surrounded with ether, and, causing this fluid to boil, the vapour passed to another cylinder, where it exerted its elastic force; and after the vapour of the ether had done its work, it was finally condensed and pumped back again to the box surrounding the external condenser of the steam engine, the condensation of the vapour of water causing another fluid (ether) to boil. This clever arrangement met with considerable approval, and has been tried on an extensive scale in the propulsion of vessels.

Superheated steam, or steam passed through a coil of iron pipe placed in the furnace, has been proposed and used successfully in the working of marine engines in order to economise fuel. Rankin calls this superheated steam "steam-gas;" and the Hon. John Wethered, of the United States, modified this superheated steam by mixing it with ordinary steam from the boiler, because he found that when the steam was heated sufficiently high to develop the full power, it destroyed the cylinder and slides. He considers the difference between superheated steam and combined steam consists in this—that the former, being of a gaseous nature, was a bad conductor of heat, and parted with it with difficulty; whereas combined steam, being pure vapour and a better conductor of heat, parted with it more readily, and left more in the cylinder of the engine to be converted into mechanical power.

Wethered claimed an economy of combined steam over ordinary steam of 52·5 per cent., and over superheated steam of 25 per cent. According to more recent experiments on the large scale, made by the eminent firm of Messrs. Penn, of Greenwich, with superheated steam, it is conclusively determined that an economy of 20 per cent. of fuel was realized in the working of marine engines, when the steam at a pressure of 20 pounds per square inch was raised by the superheating apparatus 100° Fahrenheit.

The Cornish boiler, to which allusion in connection with the Cornish engine has already been made, is shown at Fig. 182. It consists of a double cylinder, the fire being placed on bars inside it, and is one of the most useful forms that can be employed, and is the kind of boiler used for working the steam engine at the Polytechnic.

EVAPORATION.

It is so common an act to boil water and convert it into steam, that non-scientific minds are sometimes puzzled when the more learned talk of steam, or the vapour of water, being always present in the air we breathe; they begin to ask themselves mentally for the visible presence of great cauldrons of boiling water to supply the vapour; and, failing these proofs, subside into a sort of wondering doubt.

The great evaporating surfaces of the oceans, rivers, lakes, &c., are always silently at work; and Faraday, in one of his popular discourses, said that sixty sacks of coal must be burnt to produce an amount of steam such as would pass away gradually from the surface of an acre of ground during an ordinary summer's day.

The proof that the atmospheric air does contain invisible steam is shown

by the water deposited *outside* a tumbler containing iced water, or water drawn from a deep well a few degrees below the temperature of the air.

Evaporation is confined to the *surface* of the liquid exposed to the air; and that may be stopped, as in the case of water when oil is poured upon it.

If, during evaporation, vapour forms under the ordinary pressure of the air, it is necessarily increased when produced in a vacuum, because there is no resistance to be overcome; as the first is the slow production of vapour at the surface of a liquid, so the second is the quick production of vapour.

If a number of barometer-tubes are filled with mercury, and placed in a proper vessel or trough, also containing mercury, they all exhibit a height corresponding to the existing pressure of the air; when, however, a few drops of water, alcohol, or ether, or a small lump of ice, are introduced respectively into the separate tubes, the mercury is depressed immediately, showing the evaporation which instantaneously takes place in the Toricellian vacuum, or space above the level of the mercury in the barometer.

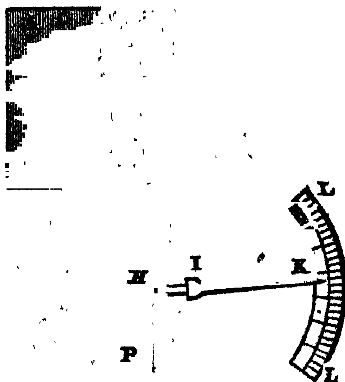


FIG. 183.—*The Catgut Hygrometer.*

The amount of depression, showing the elastic force of the vapour, varies with each liquid. At the same time, the above experiment shows that all volatile liquids are instantaneously converted into vapour in a void space, or vacuum.

Faraday found that there was a limit even to evaporation, and, experimenting with mercury, he noticed that a slip of gold leaf, suspended in the neck of a bottle containing mercury, was whitened by the evaporation and condensation of the quicksilver upon the gold. This effect did not, however, take place at a temperature of about 39·2° F. With sulphuric acid, which is a very permanent fluid, the temperature of the limit of evaporation was found to be much higher, viz., about 86° F.

Various instruments have been devised, from the earliest times of scientific investigation, to determine the quantity of invisible steam or moisture in the air. All cords, and especially catgut (a string made from the peritoneal linings of the intestines of the sheep), lengthen or shorten according to the state of the moisture in the air.

If a piece of catgut, made fast at one extremity, be conveyed, as in Fig.

183, over a series of pulleys, A, B, C, D, E, F, G, so as to make several turns backwards and forwards, and if a weight, P, be suspended from the other extremity, the latter will fall as the string lengthens in damp weather, and rise as the air becomes drier. This is shown better by attaching an index or pointer, H K, turning on a pivot I, in such a manner that the length I K shall be greater than I H, and pointing to a graduated arc, L L.

Saussure employed a human hair for the same purpose; but all such arrangements infallibly become deteriorated by time.

M. Le Roi was the first to suggest that the temperature at which dew begins to be deposited should be employed as the measure of the moisture of the air. De Luc also proved that the quantity and force of vapour *in vacuo* are

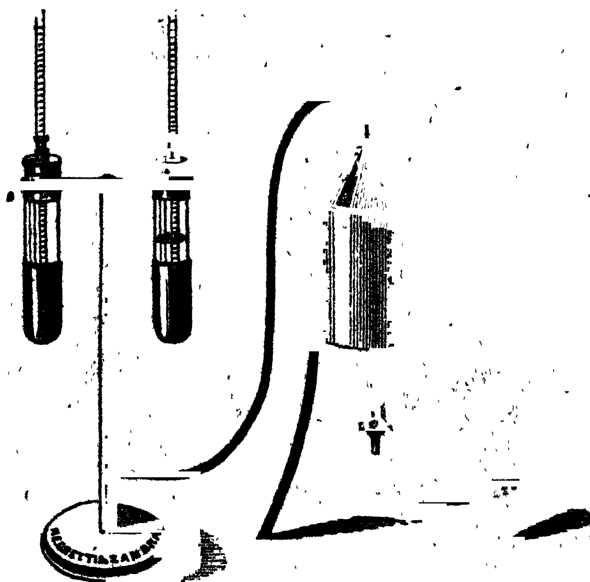


FIG. 184.—*Regnault's Condensing Hydrometer, by Negretti and Zambra.*

the same as in an equal volume of air of the same temperature, or that these two elements of vapour depend upon the temperature.

The determination of the exact temperature at which dew is formed, and at which, in the open air, the dew disappears or ceases to be formed on the sides of the vessel producing it, is of the utmost importance, and was carefully investigated by the late Dr. Dalton. The observation is rendered more exact with a bright metallic vessel, as in Regnault's elegant apparatus.

Regnault's Condenser Hygrometer consists of two highly polished silver cylinders, into the upper part of which are cemented thin glass tubes; these have brass covers, arranged to receive and support two delicate standard thermometers, the bulbs of which descend nearly to the bottom of the silver portion of these chambers. Each chamber has a small internal tube carried

down from the brass to within a short distance of the bottom, to admit the passage of the air, which is drawn through both chambers by an aspirator, connected to the base of the hollow upright and arms supporting the cylinders. To use this hygrometer, ether is poured into one chamber sufficient to cover the bulb of the thermometer, and then the thermometers being inserted into both cylinders, the instrument is now connected to the aspirator, and by it the air is drawn through both cylinders down the internal tubes, passing in one chamber in bubbles through the ether, and in the other chamber simply around the thermometer. The tube in this empty cylinder is of such a diameter as to ensure similar quantities of air passing through each chamber.

After a short time the passage of the air through the ether will cool it down to the dew-point temperature, and the external portion of the silver chamber containing the ether will become covered with moisture. The degree shown by the thermometer in the ether at that instant will be the temperature of the dew-point; the second thermometer showing the temperature of the air at the time of observation.

The late Professor Daniell, who paid much attention to the construction of hygrometers, and, indeed, constructed one of the best and most simple, says: "The more accurate mode of expressing the moisture of the air from an observation of the temperature and dew-point is by the quotient of the division of the elasticity of vapour at the real atmospheric temperature by the elasticity at the temperature of the dew-point; for, calling the term of saturation 1000, as the elasticity of vapour at the temperature of the air is to the elasticity of vapour at the temperature of the dew-point, so is the term of saturation to the observed degree of moisture. Thus, with regard to the observation in the Deccan, where, with a temperature of 90° F., the dew-point has been seen as low as 29°, making the degree of dryness 61.

Force at 90°.	Force at 29°.		
1·430	0·194	1000 :	135

The fourth term is the degree of moisture on the hygrometric scale."

RADIATION.

It is not at all surprising that the philosophers who first commenced experiments with heat, or caloric, should have regarded it as an imponderable and highly elastic fluid, which clothed, as it were, the material particles of solids, fluids, and gases; the latter attracting the former, and sometimes emitting or throwing out their caloric, which was also supposed to be repulsive of its own particles. The material theory of heat is, however, not tenable: when we consider it as radiant matter, we are reminded at once of its analogy to light, and we understand that the undulations of the same ethereal medium may propagate heat as well as light: it is not necessary to suppose that the ether which gives us light is interpenetrated by another kind of ether that may give us heat. The examination of the invisible heat rays in the solar spectrum assist us greatly in taking a correct view of the phenomena.

Whilst enjoying the social pleasures of the fireside, we are always reminded that heat can travel, like light, through space.

At night, if travelling in a steamboat across the Channel, we approach the funnel, from which *invisible* heat is constantly radiating, we see no fire, and

yet we can understand by the pleasant warmth experienced that waves of heat may be impinging upon us, just as the waves of water dart against the sides of the vessel. We shall find presently that light-waves may be separated from heat-undulations; and even when they travel together, and the light only is apparent, the heat may be rendered evident in various ways, as in the use of the burning-glass, or, by permitting the rays of the sun to pass through a glass containing some ether, the rays are freely transmitted, but if a piece of charcoal is placed in the ether, the heat rays are arrested, and vibratory power is soon conferred upon the charcoal, which in its turn communicates motion to the ether, and raises it to the boiling-point.

The intensity of the heat rays decreases or increases according to the same law which affects light, viz., as the square of the distance inversely. The intensity of heat is less, the greater the obliquity of the rays with respect to the radiating surface. Avoiding a source of heat which may be accompanied with light, and using a canister filled with boiling water, and placing it in the focus of a polished concave metallic reflector, the rays are collected, and can be thrown off to another reflector, when they are again brought to a focus, discoverable by an air-thermometer (p. 147.)

At the Polytechnic a small bit of meat can be cooked when placed in the focus of a large concave reflector, and opposite to another standing 100 ft. away, and containing in its focus a large wire cage full of burning charcoal.



FIG. 185.—*The large Polytechnic Metallic Reflectors.*
A fire in the focus of one, and the meat in the focus of the other.

The power of reflecting heat rays is influenced by the condition of the surface. Polished metals possess the property in the highest degree; and if the bit of meat were covered with gold leaf it would not be warmed through, whilst the opposite effect of first blackening the meat, by dusting finely powdered charcoal over it, assists the absorption of the heat rays very greatly. Melloni discovered that out of 100 rays

Silver	reflects	90
Bright lead	„	60
Glass	„	10

Hence, if a glass concave mirror is used to reflect the rays of an ordinary fire towards the face, little or no warmth is experienced; on the other hand, a concave tin plate will reflect the heat very sensibly.

It was formerly supposed that the power of a body to absorb heat was in the inverse proportion of its power to throw off or reflect heat—that the two properties exactly accounted for the heat originally falling upon any given surface. This, however, is not found to be the case. The heat waves which are incident upon any given surface are disposed of in three ways:

I. Some portion is absorbed.

II. Another portion is reflected according to the ordinary laws which govern the reflection of light.

III. A third portion is scattered, and is then called diffused heat.

The thinnest film of gold leaf will protect the parts of a sheet of paper exposed to radiation from some red-hot surface, whilst the blackening of any portion of the same sheet of paper will hasten its destruction.

Radiation and absorption, according to the experiments of Leslie, are directly proportioned to each other; a blackened tin vessel full of hot water, that will radiate heat freely, and soon fall to the temperature of the air, will, on the other hand, as rapidly increase in temperature if held near any good source of heat.

The relation between radiation, absorption, and reflection, and the manner in which the two first may balance each other, was elegantly shown by the late Dr. Ritchie. He used for his experiments a metallic vessel filled with hot water, and a differential thermometer, one bulb of which was shielded by a bright metallic disc, and the other with a blackened one; one surface of the metallic box containing the water was also polished, and the other blackened. When the blackened side of the box was placed opposite to the bright metallic screen, no effect was produced on the thermometer, because the radiating power of the black surface was neutralized by the non-absorptive and good reflecting power of the bright metallic disc. If, however, the same side was opposed to the blackened disc, then the thermometer was affected. Similarly, but reversely, when the polished side of the box was opposed to the blackened disc, little or no effect was perceptible, because the highly polished surface did not radiate heat easily.

If boiling water be poured into two tea-pots, one of which is of bright block tin, and the other of black japanned tin, the latter cools more quickly than the former.

The air exercises a retarding power on the waves of heat which are absorbed, and, as proved by Sir H. Davy, they travel much easier through a vacuum. Davy ignited charcoal points by a current of electricity, and, placing them in the focus of a concave mirror, discovered that, when the receiver was exhausted to 1-120th, the effect upon a thermometer placed in the focus of another reflector was nearly three times as great as when the air was at its ordinary pressure.

The absorptive power of bodies was supposed to depend greatly upon the particular colour used. Franklin placed pieces of coloured cloth in the sun's rays on the snow, and found they sank into the snow or melted it in the following order:—black, blue, green, purple, red, yellow, white. Tyndall, however, has explained the cause more correctly, and has discovered that the colour has not so much to do with the effect produced as the nature of the material used for the colouring agent. Although it has been stated by Leslie that white surfaces generally reflect heat well, and absorb it indifferently, there is the curious fact, ascertained by Melloni, that white lead has quite as great an absorbent power as lampblack; and if the heat comes from boiling water (column 1), it will absorb twice as much as it would do if it came from an

incandescent platinum wire. Melloni (p. 201) filled a copper canister with water, and kept it at the boiling-point, and by means of a very delicate instrument, called the thermo-multiplier, obtained the following relative absorptive powers, as shown in column 1. If, however, the heat is derived from an incandescent platinum wire, as in column 2, the figures are different; and white lead is found to absorb a less quantity of the rays of heat when they are luminous, and Indian ink more.

	No. 1.	No. 2.
Lampblack	100	100
White lead	100	56
Isinglass	91	54
Indian ink	85	95
Shellac	72	47
Metals	13	13·5

Leslie's principle does apply to clothing, and it appears that if we imitate nature, and, like the Polar bear, wear white, we shall be warmer in winter and cooler in summer.

In running streams, and even in the Rhine, what is called "ground ice" is frequently found. This is no contradiction of the laws already explained with reference to the cooling of water. The ice is formed at the bottom of the stream, because the stones and other earthy matters forming the bed of the river emit or radiate heat when the sky is very clear; and as the water of the stream is mixed by the current, and the temperature of the bed of the river is lowered by radiation, the ice forms in spongy masses, which may rise to the surface, carrying stones and even the anchors of ships with them. The rays of heat are more readily absorbed when they fall upon bodies at angles near the perpendicular; hence the rays of the sun are hotter in summer than in winter, when they are more oblique.

If the bulb of an air-thermometer be brought near a burning hydrogen flame, its radiating power is found to be very low, although, as is well known, the heat of the flame is so great that it will quickly ignite a spiral of platinum wire; when the heat waves are set in motion, emission or radiation takes place, which will promptly affect the thermometer. Tyndall has investigated the radiating and absorbing powers of gases and vapours, and, although they are feeble, he has been able to discover that vapours and compound gases have a much greater absorbing and emitting power than any simple or elementary gas, such as oxygen or nitrogen, or when they are mechanically mixed, as in atmospheric air. Had our globe been surrounded with a gas like olefiant gas, the absorbent power would have been 240 times greater than that of oxygen. Amongst gases, those which absorb heat the most also radiate it freely.

As might be expected from the analogy between light and heat waves, the latter may be reflected, refracted, may undergo double refraction, be absorbed, and even polarized; the latter fact being proved by the use of tourmaline plates or bundles of plates of mica.

TRANSMISSION OF HEAT.

Melloni's name will ever be associated with all the more important experiments in which the course of heat-waves is traced through various media. As with light there are bodies called transparent, diaphanous, translucent or transparent, opalescent, and opaque, so with reference to the power of transmitting heat, bodies generally are divided into two classes:

I.—Diathermanous or diathermic bodies (δια, through, and θερμος, heat), permitting heat-waves to travel through their substance. Examples—rock salt and certain elementary gases.

II.—Athermanous or adiathermic bodies, which arrest or stop the progress of the heat-undulations. Examples—all liquids in variable proportions; alum in crystal and solution.

Mr. B. Stewart has shown that bodies of the first class are bad radiators of heat, but that those of the second or adiathermic class are good radiators.

It does not follow, because substances like the diamond, glass, ice, &c., ermit light-rays to pass through them, that they will also allow the heat-rays to travel through in the same proportion. Glass permits the light to pass freely through its substance, but stops a considerable number of the heat-undulations; and alum, nearly all. Rock salt is the only substance which is entitled to be placed in the first or true diathermanous class, and although it does, according to Krupland and Stewart, absorb certain of the heat-rays more than others, still at present it stands first, and is therefore used in the form of plates, prisms, and lenses for these delicate experiments. Melloni found that certain solids, cut into plates one-tenth of an inch in thickness, allowed the following percentage of heat waves from an Argand lamp to pass:

Rock salt	92, transparent
Plate glass and Iceland spar	62, „
Smoky quartz	57, nearly opaque
Transparent carbonate of lead	52, transparent
Selenite	20, „
Alum	12, „
Sulphate of copper	0, deep blue

With liquids, when the source of heat was an Argand oil lamp, and the fluids enclosed in a glass cell, the results given in Table I. were obtained. Table II. shows the results obtained by Tyndall from liquids enclosed in a rock-salt box, the source of heat being an ignited platinum wire:

	Table I.	Table II.	
Bisulphide of carbon	63	83	transparent
Olive oil	30	—	„
Chloride of sulphur	63	—	red
Ether	21	41	„
Sulphuric acid	17	41	„
Alcohol	15	30	„
Solution of alum or sugar	12	30	„
Water (distilled)	11	30	„
Water saturated with salt	—	26	

Rock salt stands in the same relation to heat, so far as transparency to

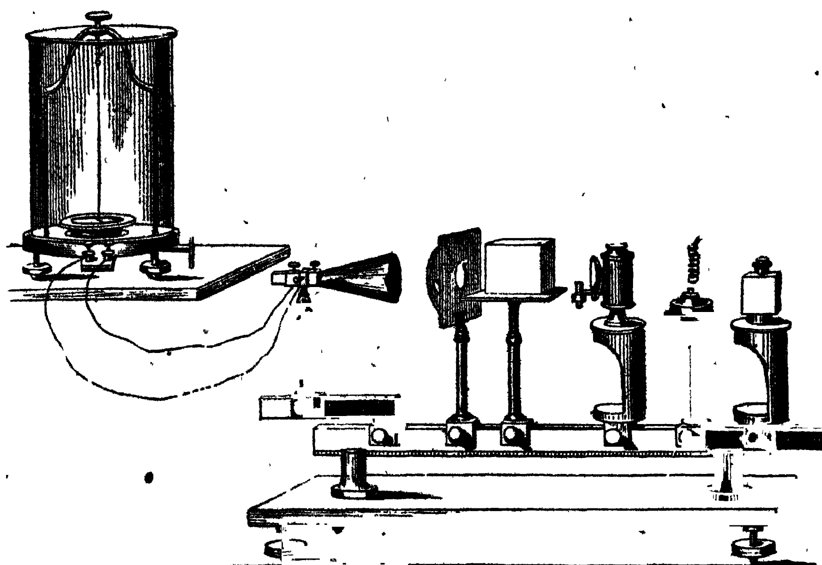


FIG. 186.—*Melloni's Apparatus.*

Argand oil lamp without a glass; spirit-lamp and platinum wire; the copper box, blackened, to contain water at 212° F.; stand, to place the objects upon, screen, with apertures of various sizes; the thermo-multiplier current, with the galvanometer needle.

heat-rays is concerned, as colourless glass does to the light-rays. When a hot metallic ball is placed between the bulbs of a differential thermometer, the liquid remains stationary, because both are equally heated; if, however, a plate of rock salt is interposed as a screen on one side of the ball, and a plate of glass on the other, the thermometer is immediately affected, as more rays pass through the rock salt than through the glass.

Melloni's apparatus for these investigations may be regarded as the model of perfection. It includes the various sources of heat, such as a naked flame, an ignited platinum wire, a blackened copper vessel containing water at 100° C. (212° F.), or a copper plate heated to 400° C. (752° F.), and is plainly shown in Fig. 186.

The delicacy of the thermo-multiplier as an indicator or measurer of heat is most remarkable, and it will be fully explained in another part of this work. The minute electrical currents set up in the thermo-multiplier are recorded by the galvanometer needle.

It has already been shown that in bodies which arrest partially or wholly the heat-waves, the nature of the heat, or rather the particular source from which it is obtained, has a great influence upon the result. Thus fluor-spar permits 33 per cent. of the heat-waves derived from boiling water to pass through its substance, whilst the power rises to 78 per cent. when the source of heat is a burning lamp. Heat-waves which have passed through one plate of glass will also pierce another, with a small amount of loss; the same waves are nearly all stopped by alum.

Tyndall's discovery, that the vapour of water absorbs thirteen times more obscure heat than air, is a most important fact, and shows why the air containing vapour nearer the earth is warmer than that which is dry and found on the summit of lofty mountains. The dry air allows the obscure heat-waves to travel through, and is too diathermanous, whilst air charged with moisture has considerable athermaneity for obscure rays, which are produced when the rays of the sun have passed through our atmosphere and fallen upon the earth. When the rays of the sun fall upon the earth to warm it, they are radiated and then diffused; a change in their quality takes place, and they become obscure rays of heat. It is these obscure rays which melt snow, and perform other useful offices.

The Conversion of Light Rays into Heat Rays, and vice versa, by Change of Refrangibility.

At the meeting of the British Association, held at Newcastle, in 1863, Dr. Akin proposed three experiments for the conversion of rays of light into heat-rays; of these one is deserving of notice, viz., the proposal to collect the rays of the sun in a concave mirror, and then to cut off the light with "proper absorbents," and to bring platinum foil into the focus of *invisible rays.*

Although Dr. Akin was the first to propose definitively to change the refrangibility of the ultra-red rays of the spectrum by causing them to raise platinum foil to incandescence, yet the chief merit, in connection with this branch of heat, is due to Dr. Tyndall, because, in the spirit of Lord Bacon, he was not content with a theory which merely suggested that a certain result might be obtained, but industriously worked out the crude idea, and proved that it was substantially true, by devising a number of clever and original experiments, which had never been shown before.

In the article on Light (p. 92), the change of refrangibility of certain rays at the violet end of the spectrum, and the beautiful experiments with "fluorescence," by Professor Stokes, have already been specially considered. And just as he obtained a large proportion of these rays, existing in and beyond the violet, by using prisms of quartz, so Melloni, by using a prism of rock-salt, was enabled to prove that the ultra-red rays discovered by Sir W. Herschel formed an invisible heat spectrum as long as the visible one. Other experimentalists continued the investigation, especially Professor Müller, of Freiberg, who worked out a curve expressing the heating power of the whole spectrum; but it was left for Tyndall to complete the investigation, and directly isolate the *invisible* or obscure rays of heat; and as Stokes, by lowering the refrangibility of the invisible ultra-violet rays, rendered them visible, so Tyndall, by raising the refrangibility of the ultra-red rays, rendered them also visible. The instruments he used, to quote his own words,* "consisted of the electric lamp of Duboscq and the linear thermo-electric pile of Melloni.

"The spectrum was formed by means of lenses and prisms of rock-salt; it was equal in width to the length of the row of elements forming the pile; and the latter being caused to pass through its various colours in succession, and also to search the space right and left of the visible spectrum, the heat falling upon it at every portion of its march was determined by the deflection of an extremely sensitive galvanometer.

* "Proceedings of the Royal Institution of Great Britain," vol. iv., part 5. Professor Tyndall, "On Combustion by Invisible Rays."



FIG. 187.—*Dr. Tyndall's Diagram.*

"As in the case of the solar spectrum, the heat was found to augment from the violet to the red, while in the dark space beyond the red it rose to a maximum. The position of the maximum was about as distant from the extreme red in the one direction as the green of the spectrum in the opposite one.

"The augmentation of temperature beyond the red in the spectrum of the electric light is sudden and enormous. Representing the thermal intensities by lines of proportional lengths, and erecting these lines as perpendiculars at the places to which they correspond, when we pass beyond the red these perpendiculars suddenly and greatly increase in length, reach a maximum, and then fall somewhat more suddenly on the opposite side of the maximum. When the ends of the perpendiculars are united, the curve beyond the red, representing the obscure radiation, rises in a steep and massive peak, which quite dwarfs by its magnitude the radiation of the luminous portion of the spectrum.

"Interposing suitable substances in the path of the beam, this peak may be in part cut away. Water, in certain thicknesses, does this very effectually.

"The vapour of water would do the same; and this fact enables us to account for the difference between the distribution of heat in the solar and in the electric spectrum. The comparative height and steepness of the ultra-red peak in the case of the electric light are much greater than in the case of the sun, as shown by the diagram of Professor Müller. No doubt the reason is, that the eminence corresponding to the position of maximum heat in the solar spectrum has been cut down by the aqueous vapour of our atmosphere. Could a solar spectrum be produced beyond the limits of the atmosphere, it would probably show as steep a mountain of invisible rays as that exhibited by the electric light, which is practically uninfluenced by atmospheric absorption.

"Having thus demonstrated that a powerful flux of dark rays accompanies the bright ones of the electric light, the question arises, 'Can we not detach the former, and experiment on them alone?'

"In the author's first experiments on the invisible radiation of the electric light, black glass was the substance made use of. The specimens, however,

which he was able to obtain destroyed, along with the visible, a considerable portion of the invisible radiation.* But the discovery of the deportment of elementary gases directed his attention to other simple substances. He examined sulphur dissolved in bisulphide of carbon, and found it almost perfectly transparent to the invisible rays. He also examined the element bromine, and found that, notwithstanding its dark colour, it was eminently transparent to the ultra-red rays. Layers of this substance, for example, which entirely cut off all the light of a brilliant gas-flame, transmitted its invisible radiant heat with freedom. Finally, he tried a solution of iodine in bisulphide of carbon, and arrived at the extraordinary result, that a quantity of dissolved iodine, sufficiently opaque to cut off the light of the mid-day sun was, within the limits of experiment, absolutely transparent to invisible radiant heat.

"This, then, is the substance by which the invisible rays of the electric light may be almost perfectly detached from the visible ones. Concentrating by a small glass mirror, silvered in front, the rays emitted by the carbon points of the electric lamp, we obtain a convergent cone of light. Interposing in the path of this concentrated beam a cell containing the opaque solution of iodine, the light of the cone is utterly destroyed, while its invisible rays are scarcely, if at all, meddled with. These converge to a focus, at which, though nothing can be seen even in the darkest room, the following series of effects may be produced:

"When a piece of black paper is placed in the focus, it is pierced by the invisible rays, as if a white-hot spear had been suddenly driven through it. The paper instantly blazes, without apparent contact with anything hot.

"A piece of brown paper placed at the focus soon shows a red-hot burning surface, extending over a considerable space of the paper, which finally bursts into flame.

"The wood of a hat-box similarly placed is rapidly burnt through. A pile of wood and shavings, on which the focus falls, is quickly ignited, and thus a fire may be set burning by the invisible rays.

"A cigar or a pipe is immediately lighted when placed at the focus of invisible rays.

"Discs of charred paper placed at the focus are raised to brilliant incandescence; charcoal is also ignited there.

"A piece of charcoal, suspended in a glass receiver full of oxygen, is set on fire at the focus, burning with the splendour exhibited by this substance in an atmosphere of oxygen. The invisible rays, though they have passed through the receiver, still retain sufficient power to render the charcoal within it red hot

"A mixture of oxygen and hydrogen is exploded in the dark focus, through the ignition of its envelope.

"A strip of blackened zinc-foil placed at the focus is pierced and inflamed by the invisible rays. By gradually drawing the strip through the focus, it may be kept blazing with its characteristic purple light for a considerable time. This experiment is particularly beautiful.

"Magnesium wire, presented suitably to the focus, burns with almost intolerable brilliancy.

"The effects thus far described are, in part, due to chemical action. The substances placed at the dark focus are oxidizable ones, which, when heated sufficiently, are attacked by the atmospheric oxygen, ordinary combustion

* "The glass in thin layers had a greenish hue: I have since found black glass far more diathermic."

being the results. But the experiments may be freed from this impurity. A thin plate of charcoal, placed *in vacuo*, is raised to incandescence at the focus of invisible rays. Chemical action is here entirely excluded. A thin plate of silver or copper, with its surface slightly tarnished by the sulphide of the metal, so as to diminish its reflective power, is raised to incandescence either *in vacuo* or in air. With sufficient battery-power and proper concentration, a plate of platinized platinum is rendered white hot at the focus of invisible rays; and when the incandescent platinum is looked at through a prism, its light yields a complete and brilliant spectrum. In all these cases we have, in the first

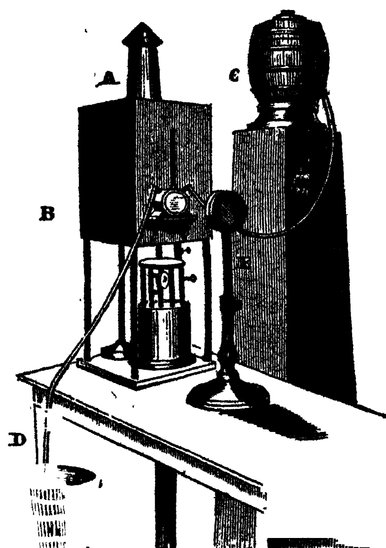


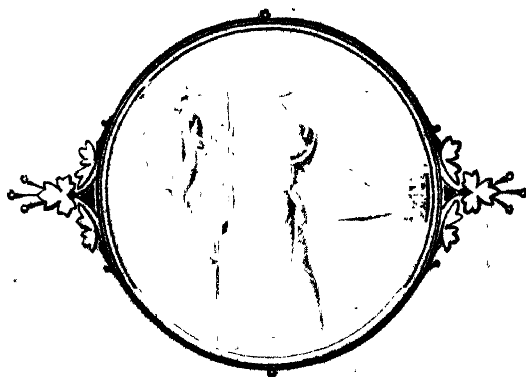
FIG. 188.—*Tyndall's Apparatus for showing the heating-power of the Invisible Rays.*

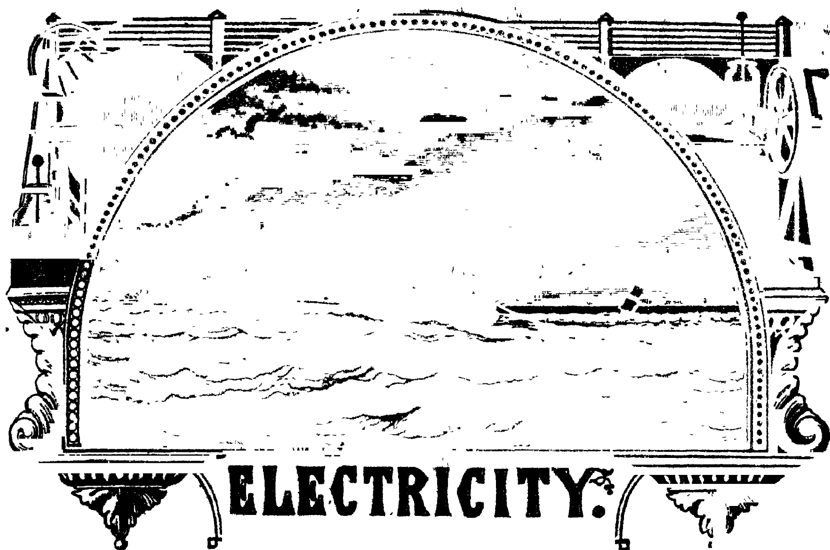
A, the lantern containing the electric lamp and silvered mirror; B, the plate-glass trough, having an outer jacket, through which cold water circulates, to prevent the solution of iodine in bisulphide of carbon boiling; C, the cistern of water and pipe passing to jacket, B, and flowing away to D; E, stand to carry zincfoil.

place, a perfectly invisible image of the coal-points formed by the mirror; and no experiment hitherto made illustrates the identity of light and heat more forcibly than this one. When the plate of metal or of charcoal is placed at the focus, the invisible image raises it to incandescence, and thus prints itself visibly upon the plate. On drawing the coal-points apart, or on causing them to approach each other, the thermograph of the points follows their motion. By cutting the plate of carbon along the boundary of the thermograph, we might obtain a second pair of coal-points, of the same shape as the original ones, but turned upside down; and thus by the rays of one pair of coal-points,

which are incompetent to excite vision, we may cause a second pair to emit all the rays of the spectrum.

"The ultra-red radiation of the electric light is known to consist of ethereal undulations of greater length, and slower periods of recurrence, than those which excite vision. When, therefore, those long waves impinge upon a plate of platinum, and raise it to incandescence, their period of vibration is changed. The waves emitted by the platinum are shorter and of more rapid recurrence than those falling upon it; the refrangibility being thereby raised, and the invisible rays rendered visible."





ELECTRICITY,

FRICTIONAL OR STATICAL.

THERE is no branch of science more fascinating to the youthful mind than this most curious form or mode of motion.

By motion it is evoked. There is nothing more to do than to rub some body, such as glass or sealing-wax, with silk or flannel, or to lay a warm sheet of brown paper on a tea-tray, and rub it well with india rubber; and the electric force becomes apparent, either by creating motion again, causing light substances, such as feathers or the down of feathers, to move towards the surface on which the force has been set free, or if observed in a darkened room, the sheet of brown paper is found to give light, a crackling sound is heard, and small sparks are visible as the sheet of paper is drawn up from the tea-tray.

This can be done over and over again. It is only necessary to dry the paper by holding it before the fire, and the same attractive power, the same curious fire, is apparent. The sheet of paper itself, after being well rubbed, will move towards the body of the person who holds it up by one corner, and is said to be attracted because it is electrified or electrized.

One of the "seven wise men of Greece," named Thales, from whose school at Miletus, in Ionia, came Socrates and his disciples, has always been considered as the first who introduced a scientific method of philosophising among the Greeks, 600 years before the Christian era.

To this philosopher is ascribed the following:

"That God is the most ancient being, who has neither beginning nor end; that all things are full of God; and that the world is the beautiful work of God."

A principle of motion, wherever it exists, is, according to Thales, *mind.*

Hence he taught that the magnet and amber (ηλεκτρον) are endued with a soul, which is the cause of their attracting powers.* It is from the Greek name of amber, a fossil resin, that the science derives its name—"Electricity."

There are many substances which are electrized by friction—gutta-percha, the skin of a cat, sulphur, the different resins, and especially shellac, the chief constituent of good sealing-wax, glass, and the greater number of crystals, &c. On the other hand, there are many bodies, such as the metals, in which, apparently, the power cannot be developed.

The earlier experimentalists divided all bodies into electrics and non-electrics: the former they considered could be electrized by friction; the latter, apparently, not so. It was then discovered that this classification was not a correct one, and that the reason the so-called non-electrics did not show any electrical energy when rubbed was because of their "conductivity;" as fast as the electricity was produced, it was conducted away to the earth and lost. Finally, they discovered, by cutting off the conducting communication with the earth by attaching the so-called non-electrics, such as a rod of metal to one of glass and then rubbing it, that now the metal could attract light particles —down, pith of the elder, gold leaf, &c.—and was then said to be "insulated." An instrument had now to be invented to indicate the disturbance of electrical equilibrium: this instrument was appropriately called an "electroscope," or instrument for showing electrical excitation. Commencing with the more simple forms, we may trace them up to the most refined and delicate instruments.



FIG. 189.—*A simple form of Electroscope.*
A, the needle and cork; B, the cup attached to the feather.

I. The mouth of a clean, dry, empty wine-bottle is closed with a cork, through which a short needle has been passed, the point being up-

* "Enfield's History of Philosophy," p. 82.

wards. On this point is balanced an eagle's feather, to which a little cup made of glass, or any other convenient hard substance, has been fixed. The glass cup, or cap, with the feather attached, resting on the point of the needle, offers little or no resistance or friction, and hence the feather moves freely like a suspended magnet in any direction.

When a stick of sealing-wax is rubbed and advanced towards the feather, the latter is immediately attracted, and will follow the sealing-wax round with great rapidity.

After the feather has been touched several times by the electrized wax, it is now found, on approaching the electrified sealing-wax, that the feather is repelled—not so energetically as it was attracted, but quite sufficiently so as to be distinctly apparent.

"Attraction" and "repulsion" are thus illustrated:

II. A glass tube or rod is bent at right angles, and the end fixed to some convenient support, viz., a round or square piece of wood. A pith-ball suspended from it by a silk filament becomes a sensitive and simple electroscope or electric pendulum.

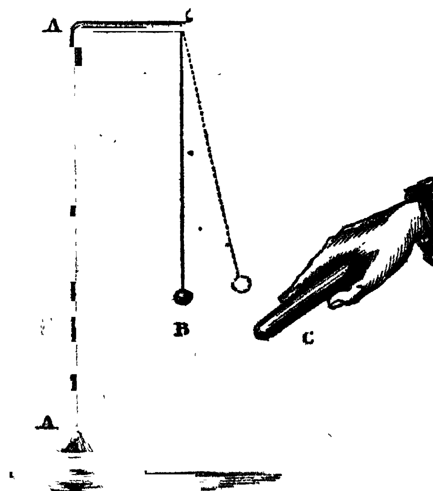


FIG. 190.—*An Electroscope.*

A A, the glass support; B, the pith-ball suspended; C, the electrized glass.

If two balls are suspended side by side, and the electrified wax or glass brought towards them, they are found, after being attracted to and touching the electrized glass, to repel each other.

"Attraction" and "repulsion" are again demonstrated:

Another modification of the above may be arranged by making two similar supports, like that in Fig. 190, and suspending a pith-ball from each. If the two balls placed close together are electrized, they repel each other; but if the two stands are moved a little way from each other,

and one electrized with the rubbed glass and the other with the rubbed wax, the two balls attract each other.

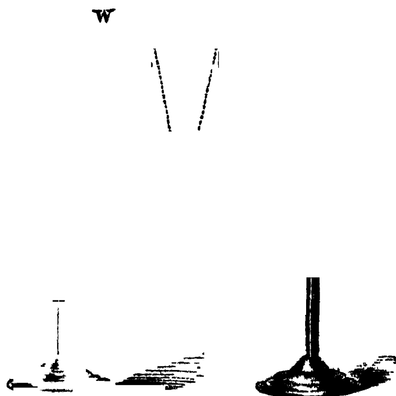


FIG. 191.—*The two Stands and Pith-balls.*
G is electrified with the rubbed glass; W, with the rubbed wax.

N.B.—A little tinfoil neatly pasted round the joints where the threads are suspended assists the accumulation of electricity; and if the pith-balls are gilt and suspended by very fine hair-like wires of silver or gold, the effects are more decided—the pith-balls do not cling together.

In this experiment it would appear that the electricity from glass attracts that from the wax; whilst separately (Fig. 190) they are mutually repulsive of their own particles, and hence one electricity was called vitreous and the other resinous.

A very delicate electroscope is that in which the material to be moved by the electrical force is itself remarkably light, and must be screened from the air to prevent it being agitated or blown off by any current of wind suddenly impinging upon it. The material is gold leaf, which can now be purchased in books cut ready for use. It is usual to attach two gold leaves to the opposite sides of a thin plate of brass, or card covered with gold paper; this is held by a pair of pincers, at the end of a brass rod passing through a glass tube cemented in a brass cap, attached to a bell-glass. By this mode of suspension the brass wire, which terminates with a circular brass plate or table, is supported on the glass tube (a bad conductor of electricity), and the tube and cup are again supported by the bell-glass, so that good insulation is secured. When great refinement is required, it is usual to place a glass shade over the whole; the latter is perforated at the top with a hole, about one inch in diameter, through which the brass rod and table are passed, and lumps of lime being placed in both glasses, the air is kept dry, and, the aqueous vapour being absorbed, there is no deposit of dew-like moisture under either of the glasses. (Fig. 192.)

A, brass table or disc, with wire attached, and pincers P, to hold the gilt card to which the gold leaves are attached; C, the inner bell-glass,

upon which the cap carrying the glass tube D, through which the brass rod passes, is cemented; E E, the outer glass shade, perforated with a hole in the top, about 1 in. in diameter, to allow the brass rod to pass through, N.B.—The table or round plate unscrews from the wire, in order to allow this to be done: both the inner bell-glass and the outer glass shade fit nicely into grooves made in a square mahogany stand, G G, neatly fitted with a drawer to hold quicklime. The part of the stand covered with the two glasses is perforated with holes, in order that the desiccating power of the lime may take full effect on the air enclosed by the two glasses. It is sometimes usual in this electroscope, called Bennet's, to place two rods and balls in the stand; so that, if the gold leaves are too highly charged, they may not be torn off, but, by touching the brass rods, the excess of electricity, which might damage

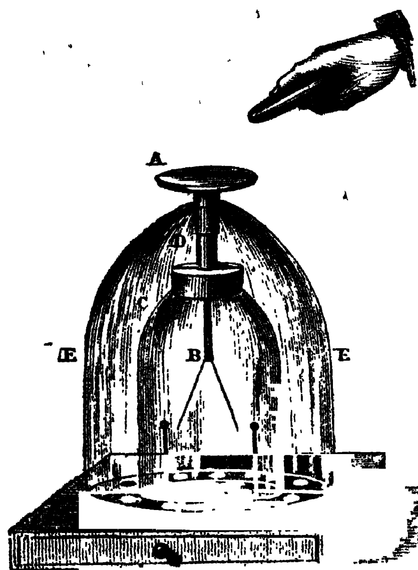


FIG. 192.—*A more delicate Electroscope.*

the instrument, is carried off to the earth. For other reasons, the brass rods connected with the earth exalt the power of the electricity applied, however feeble it may be.

An electrized glass rod, brought towards the cap of the instrument, causes the gold leaves to diverge or repel each other; when left divergent with the electricity from glass, they instantly fall on the approach of an electrized piece of wax. The little table is convenient for standing any object on; or else a plain ball would perhaps be a better terminal, as the edges of the table, unless nicely rounded, are apt to dissipate the electricity.

It is not necessary to touch the cap of the electroscope with the

electrized bodies, in order to pass into or on the rod connected with the gold leaves the electricity we wish to examine. By an influence called "induction," to be more fully explained hereafter, the gold leaves are found to possess the same kind of electricity as that enjoyed by the electrized body.

Another electroscope invented by Dr. Robert Hare, of the University of Pennsylvania, in which one gold leaf only is used, is worthy of particular notice here, and is described in Noad's "Manual of Electricity:"

"The leaf, about 3 in. long and 3-10ths of an inch wide, is suspended, according to Singer's method, in the centre of a globular or other shaped glass vessel from a brass wire surmounted with a brass cap. A similar rod of brass, carrying at each end a small disc of brass or gilt wood, about half an inch in diameter, passes through the side of the vessel, so that the internal disc shall be immediately opposite the lower end of the suspended leaf. This wire slides freely through a socket, so that the internal disc may be adjusted at any required distance from the leaf.

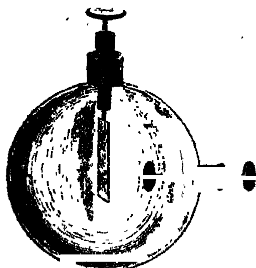


FIG. 193.
Dr. Robert Hare's single-leaf Electroscope.

"When it is employed to detect electricity, the lateral wire is uninsulated by hanging a wire from it to the earth, and the body to be tested is brought into contact with the cap. If the distance between the gold leaf and the disc B is very small, the most minute force of attraction is rendered apparent. When it is required to determine the *kind* of electricity with which a body is charged, the insulated disc B is brought as near as possible to the leaf, and electrified either *positively* (with excited glass) or *negatively* (with excited wax); the gold leaf is first attracted, and then repelled. Under these circumstances the body to be tested is brought into contact with the cap or with D: if its electricity be of the same nature as that with which the leaf is charged, the latter will diverge more freely; if of the contrary nature, it will collapse towards B.

"By placing a gilt disc on each side of the gold leaf, Mr. Gassiot obtained signs of electrical excitation from a single cell of the voltaic battery."

From the preceding experiments the following conclusions may be arrived at:

I. That an electrified body has the power to attract another which is not electrical.

II. That two bodies similarly electrified repel each other.

III. That the electricity derived from glass is different from that obtained from wax; and that, being dissimilar, they attract each other.

IV. The two electricities have names to distinguish them from each other: one is called vitreous, because obtained from glass; and the other resinous, because usually obtained from sealing-wax. The whole is summed up in the two simple statements:—Similar electricities repel each other; dissimilar electricities attract each other.

V. The electricity a substance gives out by friction is not always the same, but depends on the nature of the rubber used, and other circumstances.

Glass, when rubbed with a cat's skin, gives resinous electricity, and vitreous if rubbed with silk. Polish and temperature, as shown by De la Rive, exercise a remarkable influence. When bodies are highly polished, they have a greater tendency to give by friction vitreous electricity, or to acquire it; by elevating the temperature of bodies, they have a greater tendency to acquire resinous electricity.

A piece of roughened or ground glass, rubbed against a smooth and highly polished piece of glass, becomes resinous, whilst the smooth glass is negative.

VI. No single electricity can be evolved without an equal excitation of the other or opposite electrical force; the rubber and the substance rubbed are always in opposite states—the silk handkerchief being resinous, the glass vitreous.

Electricity being, as it were, a resident in all substances, it is said to be quiescent when the two opposite forces have neutralized each other. It is then called the static state of electricity; and this state is supposed to be the normal condition of all bodies before they become electrical.

When the two electricities travel towards each other, or pass in sparks through intervals of air, or move insensibly along a wire or other conductor, it is said to be in a dynamic state, or condition of motion or circulation, which becomes very evident in watching the motion of an electrical machine, or the single voltaic circle of zinc and copper placed in acid and water. The dynamic state is sometimes spoken of as electric tension, and an electric current as a *continuous dynamic state.*

THEORIES OF ELECTRICITY.

By the theory of Du Fay, as altered by Symmer, it is supposed that two forces, called *fluids*, exist in every substance, whatever may be its nature—solid, liquid, or gaseous.

Each of the two fluids is supposed to be very subtile and rare, quite imponderable, and consisting of particles that repel each other.

When the two fluids are separated, electrical effects are obtained; and when they unite, the electrical power ceases, for they have now combined to form neutral fluid, or natural electricity. As before stated, one electricity is called vitreous, and the other negative.

The repellent nature of the electrical particles is supposed to cause them to arrange themselves on the surface of conducting bodies, where they remain, because they are checked in their movement by the non or badly conducting air with which they are surrounded.

Non or bad conductors are supposed to retain the fluids, and to interfere with their movements.

This theory of Symmer is a most convenient and simple one for the young student, and will help him to fix the main experimental truths of electricity in his mind.

The second theory, devised by Benjamin Franklin, supposes that *one* fluid only exists, the particles of which mutually repel each other. The electrical fluid is supposed to be combined with all matter: matter without electricity is supposed to be repulsive of its own particles. When a body is in a quiescent

electrical state, then the matter is exactly saturated with electricity, and it is in a natural condition.

If the substance is rubbed, it either gains or loses the electrical fluid. The acquisition of more electricity is said to confer a plus or positive state of electricity: the loss of the electricity places the substance in a minority with regard to electricity; it is now said to be indued with minus or negative electricity.

What Symmer terms vitreous electricity Franklin calls positive electricity; what Symmer styles resinous electricity is called by Franklin negative electricity..

It is of little consequence which theory we adopt, for one or the other must be wrong; most likely, both are untrue. We have seen that a certain vibration of particles will produce invisible heat rays, and, when they are quickened in their pulsation, light rays; as in Tyndall's experiments, the concentrated invisible rays of heat, falling on a piece of platinum-foil, are converted into visible or light rays. The same wave theory will doubtless be ultimately applied to electricity, which may only be some remarkable vibratory state of the ether pervading all matter and space. And this opinion was held, forty years before Galvani, by Sultzer, who first experimented with pieces of silver and lead. By placing them on opposite sides of the tongue, and then bringing the two in contact, he noticed a peculiar metallic taste, like vitriol.

Here again it will be understood why so much space was devoted to the consideration of the "universal ether," at the commencement of the article on Light.

EXPERIMENTS WITH THE ELECTROSCOPE.

An electroscope is easily made with a wide, clean lamp-glass. A cork is fitted into it, and through the cork is passed a wire, one end of which is beaten out, so as to give a sufficiently large and flat surface; a pair of small gold leaves are attached to this end of the wire, and to the other is fixed a round piece of cardboard, covered with tinfoil or gold paper. When the wire is passed through the cork, the gold leaves may be attached by moistening the flattened end of the wire with a little gum, and bringing it carefully down upon the cut gold leaves in the book. The second gold leaf is the most difficult to get on. When both leaves are in their places, the cork, wire, and leaves may be placed in the lamp-glass, and the cardboard table fixed on the wire.

I. A little coffee, quickly ground in a mill, received in a warm dry beaker glass, and then sprinkled upon the table or plate of the electroscope, causes the leaves to diverge.

II. Some whiting or chalk, dried and put into the valve of a pair of bellows, and then forced out upon the electroscope with the wind, very soon causes the leaves to be deflected.

III. A large lump of sugar held over the electroscope, and sawed in various places with a saw, affects the instrument as the sugar-dust falls upon it.

IV. After playing a tune on a violin with a dry and well rosined bow, if the latter is passed lightly over the electroscope, electrical excitation is apparent.

V. A roll of dry warm flannel rubbed against a stick of sealing-wax

causes the leaves of the electroscope to stand out, and repel each other; but they fall directly the sealing-wax is applied, because the two electrical and opposite forces—vitreous from the flannel and resinous from the wax—neutralize each other, the rubber and the substance rubbed giving always the opposite states.

VI. While the leaves are divergent with the rubbed wax, bring an excited glass rod or tube towards the electroscope, as before; the leaves fall immediately.

VII. Mr. Symmer, whose name has already been mentioned in connection with one of the theories of electricity, tried some very amusing experiments with silk stockings. He put upon the same leg a worsted stocking, and over that a silk one, and rubbing the outer stocking before a fire, he slipped the silk one suddenly off, and, the sides repelling each other, the stocking appeared to be inflated, and to retain the same shape as if the leg were in it; and of course, if the silk stocking had been carefully approached towards the electroscope, the leaves would have been rendered powerfully divergent.

VIII. A crystal of Iceland spar cemented to an insulating glass rod, then pressed in the hand, and placed immediately on a very delicate electroscope, will cause a slight divergence.

IX. A disc of insulated cork, gently warmed and simply pressed against another one of the same material, will show a certain minute amount of electrical energy when applied to the electroscope, the warm disc being usually resinous, and the cold one vitreous.

X. A stick of sealing-wax broken, and the fractured portion applied to the electroscope, gives abundant evidence of electrical excitation.

XI. On a sheet of mica place the end of a stick of sealing-wax whilst in the melted state, and as hot as possible; allow the stick of wax to cool and to adhere to the mica. If now the wax is suddenly pulled so as to tear away a film, the fracture will disturb the electrical quiescence of the mica, and it affects the leaves of the electroscope.

XII. A roll of sulphur broken across, and the bits powdered up in a mortar, produce a very lively effect upon the gold leaves when brought in contact with the cap or table of the electroscope.

XIII. The crystals of tartaric acid, boracite, and the tourmaline all become electrically excited when heated, and affect the electroscope. Chocolate fresh from the mill, as it curls in the tin pans in which it is received, becomes strongly electrical. When turned out of the pans, it retains this property for some time, but soon loses it by handling. Melting it again in an iron ladle, and pouring it into the tin pans as at first, will, for once or twice, renew the power; but when the mass becomes very dry, and powdery in the ladle, the electricity is revived no more by simple melting; but if then a little olive oil be added, and mixed well with the chocolate in the ladle, on pouring it into the tin pans, as at first, it will be found to have completely recovered its electric power.

M. Becquerel's experiment with heating the tourmaline is performed as follows:—The crystal of tourmaline is supported in a stirrup of paper, attached to a few filaments of silk, hung on to an insulating rod of glass, attached to an upright pillar, so that it can be moved up or down. The crystal is lowered so as nearly to touch a plate of copper,

heated below with a spirit-lamp; and resting on the plate is a cylindrical glass, open top and bottom, like a wide but short lamp-glass. Two pieces of covered bent wire, each carrying a little disc of gilt paper, are placed over the top edge of the cylinder, and so arranged that each disc shall nearly touch the end of the crystal; or, better still, the cylinder is perforated with two holes, opposite each other, and the wires cemented in with their discs, and made to face the poles or ends of the tourmaline. If each wire is separately con-

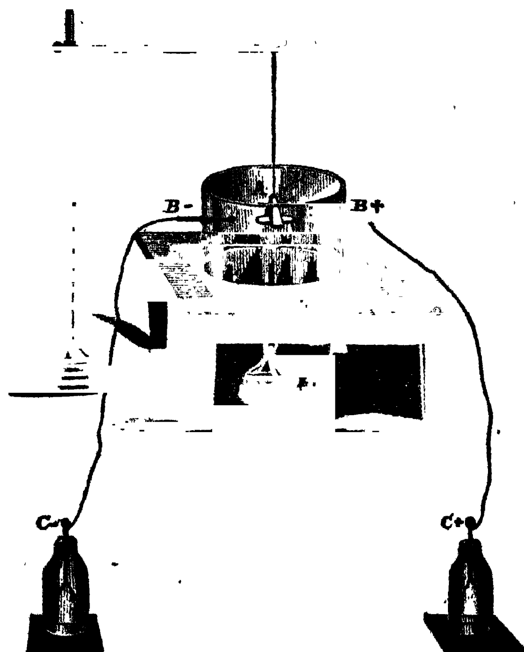


FIG. 194.—*Becquerel's experiment with the heated Tourmaline.*

A, the suspended and heated tourmaline; B+, the wire conveying the + or vitreous electricity to the electroscope C +; B —, conveying the — or negative electricity to the electroscope C —; D, the spirit-lamp heating the copper plate E.

nected with a delicate electroscope having very small gold leaves, and the crystal warmed and then raised so as to be opposite to and just touching the little gilt discs, one end of the crystal will give vitreous or + electricity, the other resinous or — electricity. The effect is most powerful whilst the temperature is rising; when the temperature becomes fixed, the electrical effect ceases. On reversing the experiment and allowing the tourmaline to cool, the electricity again becomes apparent; but the electrical poles of the crystal are reversed, the end that was + whilst being heated becoming — in

the act of cooling. If the crystal is broken, the fragments, like the parts of a broken magnet, each exhibits the opposite electricities at their extremities. M. Gaugain states that the crystal should not be heated beyond about 302° F. If raised to 752° F., the tourmaline becomes a conductor of electricity; it recovers its insulating power on cooling, but is then rendered hygroscopic; this property it again loses on being washed and dried at 302° F.

XIV. In the article on Electrical Induction, a still more delicate electroscope called Volta's condenser electroscope, and another termed Peclet's Multiplying Condenser, will be described. With the first of these instruments the electricity derived from "*chemical action*" is distinctly shown. A clean platinum capsule, containing some distilled water, is placed upon the Volta electroscope; into this is immersed a plate of zinc connected by a wire with the earth. The liquid acquires a very feeble charge of + or positive electricity, and the metal is found to be — or negative: the very slight oxidizing power of the water upon the zinc is supposed to produce this result. There is no advantage gained by the addition of a little sulphuric acid, because the conducting power of the water is increased, and the two electricities have a tendency to re-unite directly they are liberated: hence pure water is the best for this experiment.

XV. With the same electroscope (Volta's) the electricity eliminated by combustion may be rendered apparent. The carbonic acid is allowed to impinge upon a metallic plate placed in conducting communication with the instrument, the charcoal being burnt in connection with the earth. The electricity is extremely feeble, but is found to be definite, the carbon being — or negative, whilst the carbonic acid is + or positive. The combustion of hydrogen gas produces water; and in this combination of the former with oxygen, the hydrogen is found to be — or negative, and the steam + or positive.

XVI. It was contended by Pouillet—to whom we are indebted for a large number of these delicate experiments—that when water is evaporated electricity is always liberated; if the water was alkaline, it charged the electroscope with positive, if acid, with negative electricity: hence it was easy, and seemed feasible, to propose a theory which should account for the accumulation of electricity in the clouds, the enormous amount of evaporation going on from the surface of rivers, lakes, seas, being supposed to be a constant source of electric power. Peltier has shown that the electrical effects are most likely due to friction of the evaporating fluid against the sides of the vessel, as the electricity is only liberated at the last moment, when the alkaline matter is crackling against the vessel in the act of becoming solid. Moreover Faraday demonstrated that the steady evaporation of water from a platinum dish did not produce electricity; if, however, the dish was made very hot, and a large drop of water allowed to fall into it, the latter assumed the spheroidal state, and no electricity was apparent until the temperature of the platinum dish was allowed to fall, and the drop of water to boil violently and to rub against the sides of the vessel. It will be seen presently that the further development of this idea led to the construction of the powerful steam hydro-electric machine at the Polytechnic Institution.

XVII. The slow oxidation of zinc by the air has been used by De Luc, who contrived the *dry pile*. The dry pile is, however, useless if allowed really to become dry; it has been found that, when the moisture naturally present in all paper is thoroughly removed, the action of the dry pile diminishes and almost ceases, but is easily restored by the admission of damp air, which gives back to the paper its natural amount of moisture. The dry pile is usually made by arranging, in a tube capped at both ends with brass, discs of thin sheet-zinc paper or silver-foil, and the following are Mr. Singer's directions for the construction of a dry pile:

"The materials I prefer for these piles are thin plates of flatted zinc, alternating with writing or smooth cartridge paper and silver leaf.

"The silver leaf is first laid on paper, so as to form silvered paper, which is afterwards cut into small round plates by means of a hollow punch.

"In the same way an equal number of plates are cut from thin flatted zinc and from common writing-paper.

"These plates are then arranged in the order of zinc paper, silvered paper with the silver side upwards, zinc upon the silver, the paper, and again silvered paper with the silvered side upwards, and so on; the silver being in contact with zinc throughout, and each pair of zinc and silvered plates separated from the next pair by two discs of paper.

"An extensive arrangement of this kind may be placed between three thin glass rods, covered with sealing-wax, and secured in a triangle by being cemented at each end into three equidistant holes in a round piece of wood; or the plates may be introduced into a glass tube, previously well dried, and having its end covered with sealing-wax and capped with brass; one of the brass caps may be cemented on before the plates are introduced into the tube, and the other afterwards. Each cap should have a screw pass through its centre, which terminates in a hook outside. This screw serves to press the plates closer together, and to secure a perfect metallic contact with the extremities of the column."

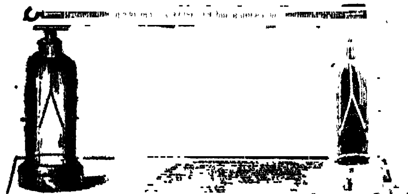


FIG. 195.—*De Luc's "Dry Pile," connected with two Electroscopes.*

If a tube containing one thousand alternations is laid upon two electroscopes, as in Fig. 195, the zinc end is found to be positive, and the silver negative. Mr. Singer continues:

"I found a series of from twelve to sixteen hundred groups, which

are arranged in two columns of equal length, which are separately insulated in a vertical position: the positive end of one column is placed lowest, and the negative end of the other, their upper extremities being connected by a wire, they may be considered as one continuous column. A small ball is situated between each extremity of the column and its insulating support; a brass ball is suspended by a thin thread of raw silk, so as to hang midway between the balls, and at a very small distance from them.

"For this purpose the balls are connected during the adjustment of the pendulum by a wire, that their attraction may not interfere with it; and when this wire is removed, the motion of the pendulum commences. The whole appararus is placed upon a circular mahogany base, in which a groove is turned to receive the lower edge of a glass shade, with which the whole is covered."



FIG. 196.
The Perpetual Chime, constructed with De Luc's columns.

Mr. Singer directs that, in order to preserve the power of the columns, the two ends should never be connected by a conducting substance for any length of time. It is therefore necessary, when laid by, that it should be placed upon two sticks of sealing-wax, and that the terminal balls be half an inch or so from the table.

If a column which appears to have lost its power be thus insulated for a few days, it will recover. There is another cause of deterioration, which is more fatal: this is too much moisture. The paper discs therefore should be made as hot as possible before they are put together; or even subjected to a continued but gentle heat for some time before they are inclosed in the glass tube, and, that being heated also, the platcs may be inclosed without the presence of any appreciable moisture.

The size of the plates may be $\frac{5}{8}$ths of an inch in diameter, or less. With a column of 20,000 alternations a Leyden jar may be charged, and minute sparks are visible when contact is made with the fine points of wire connecting the two extremities.

When the dry pile is attached to the electroscope of Hare by substituting the poles of two of De Luc's columns for the gilt disc (Fig. 193, p. 212), the instrument is made wonderfully delicate, so much so that Mr. Sturgeon describes an arrangement of this kind, the delicacy of which he states to be such that, the cap being of zinc, and of the size of a sixpence, the pendent leaf is caused to lean towards the negative pole by merely pressing a plate of copper, also the size of a sixpence, upon it, and when the copper is suddenly lifted up the leaf strikes. The different electrical states of the inside and outside of various articles of clothing were readily ascertained by this delicate electroscope. Bohnenberger has the credit of making the first of these instruments.

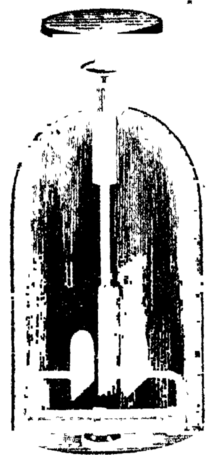


FIG. 197.—*Bohnenberger's Electroscope.*

A, the gold-leaf suspended between the two poles, B B, of the dry pile.

The gold leaf, being in equilibrium, and neither attracted or repelled, is instantly moved to one side or the other when the very smallest amount of electricity is evolved on the cap of the instrument.

From these various experiments with electroscopes it may be learned that friction under every circumstance, and even when disguised, as in the rapid evaporation of water from a hot surface, is an important source of electricity;

That there are two kinds or conditions of electricity which exactly neutralize each other, and they are always evolved together;

That pressure, or any modification of mechanical motion, such as fracture, rending, or tearing, all cause electrical quiescence to be disturbed;

That heat, as applied to various crystals, sets their particles in motion, and causes the evolution of electric force;

That chemical action is a source of electricity, of a tension similar, though not equal, to that of ordinary friction, as shown in De Luc's column.

ELECTRICAL MACHINES.

In the year 1777, Tiberius Cavallo, a thoroughly practical and learned electrician, describes, in his "Complete Treatise on Electricity," the construction of the cylinder electrical machine of his day. It will not be found to differ materially from that made in 1868. He remarks—

"The principal parts of the electric machine are the electric, the moving engine, the rubber, and the prime conductor, *i.e.*, an insulated conductor which immediately receives the electricity from the excited electric."

The electric formerly used was made of different substances, as glass, resin, sulphur, sealing-wax, &c.; and in different forms, as cylinders, globes, spheroids, &c. (Fig. 198.)

The three glass globes are made to rotate and rub against three cushions. The conductor, a piece of metallic pipe or a gun-barrel, was suspended from the ceiling by silken cords, and connected with the globes by unravelled gold lace hanging down, the latter being used for the same purpose as the points now attached to all conductors of electrical machines.

"This diversity," continues Cavallo, speaking of the various shapes and nature of the electric used, "then obtained on two accounts: first, because it was not ascertained which substance or form would answer best; and, secondly, on account of producing a negative or positive electricity at the pleasure of the operator; for, before the electricity of the insulated rubber was discovered, sulphur, rough glass, or sealing-wax was generally used for the negative elec-



FIG. 198.—*Dr. Watson's Electrical Machine,*
Showing the first application of the cushion as a rubber, instead of the hand.

tricity." The reader will perceive that Cavallo adopts the Franklinian theory. "At present smooth glass only is used; for, when the machine has an insulated rubber, the operator may produce positive or negative electricity at his pleasure, without changing the electric.

"In regard to the form of the glass, those commonly used at present are globes and cylinders.

"The cylinders are made with two necks; they are used to the greatest advantage without any axis (or rod passed through from neck to neck); and their common size is from 4 in. diameter and 8 in. long to 12 in. diameter and 2 ft. long, which are perhaps as large as the workmen can conveniently make them.

"The glass generally used is the best flint, though it is not yet absolutely determined which kind of metal is the best for electrical globes and cylinders. The thickness of the glass seems immaterial, but perhaps the thinnest is preferable.

"It has often happened that glass globes and cylinders in the act of whirling have burst in innumerable pieces with great violence, and with some danger to the bystanders. Those accidents are supposed to happen when the globes and cylinders, after being blown, are suddenly cooled.

"It will, therefore," prudently remarks Cavallo, "be necessary to enjoin the workmen to let them pass gradually from the heat of the glass-house to the atmospherical temperature."

The author prefers a single handle, instead of the multiplying gear, which is very apt to get out of order, and the cord to stretch or break when most

wanted. The various parts of the machine just described were gradually invented and applied by various clever electricians,—Otto Guericke, Hawkesbee, Abbé Nollet, Dr. Watson, Wilson, Nairne, Dr. Priestley; and many years elapsed before the machine attained anything like the perfection of that em-

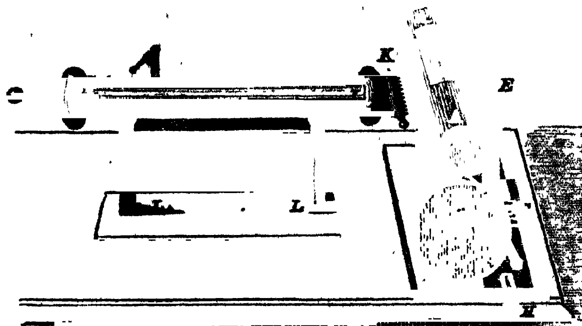


FIG. 199.—*Cylinder Electrical Machine, used by Cavallo in* 1777,

Showing the glass cylinder A A, with a pulley attached to one neck, B, round which an endless cord passes to a large or multiplying wheel, C; the cushion E, and silk flap F: the cushion, placed on a glass pillar let into a piece of wood, moves backwards and forwards in a groove, G, and is secured by a screw; before use, is covered with amalgam. The machine is clamped to the table at H. The prime conductor I I, with collecting points K, is supported on glass legs, L L, let into a mahogany stand. The amalgam used by Cavallo consisted of two parts mercury and one of tinfoil, with a little powdered chalk, all rubbed up with grease.

ployed by Cavallo in his experiments. A more elegant and compact form is now given to the cylinder machine by Messrs. Elliott, of the Strand.

The most convenient form is undoubtedly the plate electrical machine. Of this Cavallo says—

"Next to Dr. Priestley's machine, I shall describe another, which was invented by Dr. Igenhouz, and which, from its simplicity and conciseness, makes a fine contrast with the former.

"This machine consists of a circular glass plate, about 1 ft. in diameter, which is turned vertically by a winch fixed to the iron axis that passes through its middle; and it is rubbed with four cushions, each about 2 in. long, situated at the opposite ends of the vertical diameter."

Fig. 200 is a drawing of the large plate electrical machine in use at the Polytechnic. The plate glass is 7 ft. in diameter, and rather more than $\frac{6}{8}$ths of an inch thick; it has two large rubbers, and, when these are well amalgamated, and the weather is propitious—at least dry—very long sparks of great intensity may be obtained; when the atmosphere is damp, in spite of the rapidity and power with which it is turned round by a four-horse power steam engine, it will hardly give a spark an inch in length.

The prime conductor is a large globe, about 3 ft. in diameter; and inserted into this is a large ring of wood, 4 ft. in diameter, and raised 6 ft. from the globe—being an arrangement first proposed in connection with the Austrian electrical machines exhibited in the Great Exhibition of 1862. The ring, no doubt, theoretically speaking, should act as a condenser, and assist, by induction, to increase the tension of the electricity; but whether it be due to the

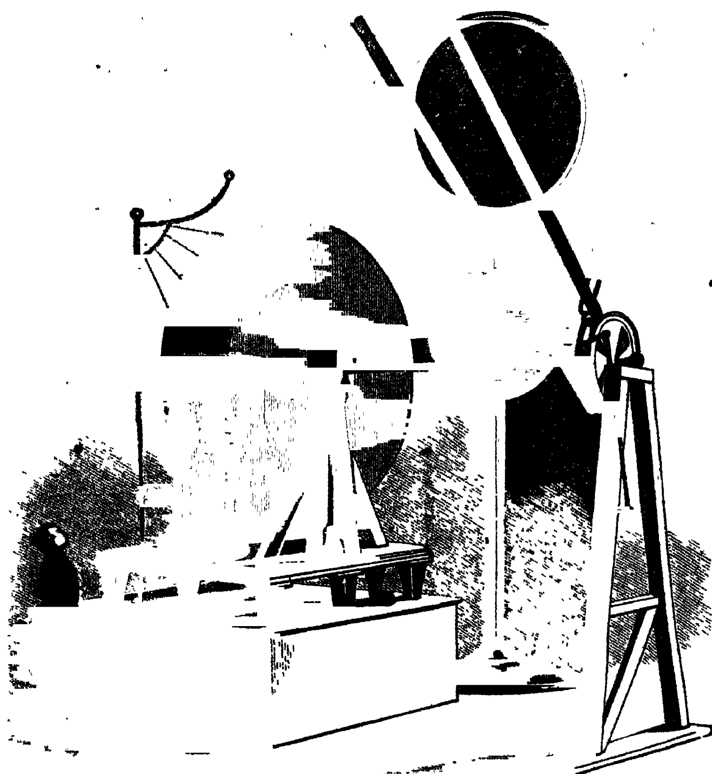


FIG. 200.—*The great Plate Electrical Machine at the Royal Polytechnic.*

height of the building in which the ring is placed, or from other causes, the effect produced did not appear to be increased by this addition to the apparatus. The power of an electrical machine is greatly influenced by the nature of the glass. There is a very fine-*looking* machine at the Polytechnic, constructed on the plan of the late Sir William Green Harris: the plate is 3 ft. in diameter; but, in consequence of the alkali of the plate glass, its power is very slight, and not half so good as that of many small cylindrical machines.

The best amalgam for an electrical machine is made of 1 part of tin, 2 of zinc, and 6 of mercury. Melt the zinc and tin together, and, when approaching solidification, add the mercury, and stir till the whole is solid: if the latter is added when the alloy of zinc and tin is too hot, much of it may be dissipated in vapour; and the amalgam should be made under a chimney, to avoid the fumes of mercury. Sometimes the above are rapidly melted together, and then placed in a wooden box and shaken until quite cold. The shaking reduces the greater part to a fine powder, which may be sifted out and used

with grease. The author always lays a coating of tallow-grease on the cushion first, and then carefully sifts the amalgam upon it, laying all smooth with a clean broad knife or spatula.

Very cheap machines can be made from common window-glass, to the centre of which, and on the opposite sides, two wooden caps, turned convex, may be cemented without any perforation of the plate, the axle being made of glass rod fitting into holes in the wooden caps. Mr. Goodman recommends that the cement used should be made of equal parts of black resin and beeswax; but the writer recommends the use of less beeswax, because it renders the cement liable to melt easily if the electrical machine is placed before a fire to be warmed; the quantity may be 1 lb. of black resin to 3 oz. or 4 oz., at the most, of beeswax. A plate of this kind would cost half-a-crown. Sometimes two circles of common window-glass are cemented together to increase the thickness, and prevent the chance of breakage. The common window-glass, from its hardness, gives a large quantity of electricity when the friction is properly and equally applied. Very excellent machines are now made of plates of vulcanite, and, in fact, are used for mining purposes. The plate is enclosed in a box of vulcanite, and turned by a handle on the outside. It contains one or more Leyden plates; and after these are charged by a few turns of the machine, the discharge may be sent through covered wire into one of Professor Abel's fuses at a distance of many hundred yards. The writer has used such a machine on a damp night in November, in the grounds of Haileybury College, Herts, with the greatest success, exploding three separate charges—one of gunpowder, directed against a heavy gate; another, a mine, blowing many tons of earth into the air; and a third, a keg of 9 lbs. of gun-cotton, made by Messrs. Prentice, of Stowmarket, which nearly emptied a pond in which it was exploded, and, sad to relate, broke a great many windows in the chapel by the terrific concussion of the air, although the building was at least three hundred yards from the pond where the explosion took place. Mr. Hart, of Edinburgh, describes a very compact and well-arranged machine, called Winter's Electrical Machine.

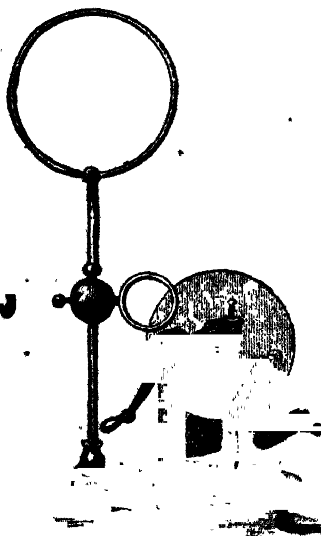


FIG. 201.
Winter's Electrical Machine.

Winter's Electrical Machine is one of the most perfect forms of the plate friction machine that has hitherto been made. It distinguishes itself from other machines by the extraordinary length of the spark that it gives, by simplicity of construction, and by the uniformly good results that are obtained from it, even when the state of the air is not favourable to the display of electrical phenomena. The annexed drawing represents one of these instruments. It

will be seen from it that the glass plate is fixed into an axle, which revolves in two upright supports. One of these, in which the shorter wooden end of the axle revolves, is made of glass, and the other, in which the longer glass end of the axle revolves, is made of wood. By this means the electricity formed upon the plate cannot on either side reach the ground, for on the one side the insulating glass pillar, and on the other the insulating glass axle, prevents it, and thus complete insulation of the plate forms one of the elements of the excellence of Winter's machine. The friction in this, as well as in all friction-machines, is caused by pressing on the plate of glass a flat surface of leather, covered with an amalgam of mercury, zinc, and tin, which is put on with the aid of a little grease. The frame standing on the low glass support to the right of the figure is the wooden rubber frame, into the notches of which fit two flat pieces of wood covered in front or on the side next the plate with leather and a very little stuffing, and provided on the other side with springs, which, acting against the frame, keep the front surface uniformly pressing against the plate. There is only one pair of rubbers, not two, as in ordinary machines, and this enables them to be placed at a greater distance from the prime conductor of the machine. The brass ball standing on the tall glass support to the left is the prime conductor. For the sake of more perfect insulation, this ball is fitted on to the support by means of a trumpet-shaped opening made in it, thereby preventing the dispersion of electricity that would arise from the sharp edge of a hole exactly large enough for the rod. There are three other openings in this ball, one on each side and one at the top. The two small rings which are seen projecting upon the plate fit into one of these by means of a T-shaped piece of brass. They are made of wood, and have a groove cut in them on the side turned towards the plate, into which a row of fine pin-points is fixed for collecting the electricity formed upon it. These points are connected with the prime conductor by means of a strip of tinfoil which lines the bottom of the groove. Two wings of oiled silk attached to the rubbers stretch between them and these rings, so as to prevent the electricity from dissipating itself before reaching them. The opening on the top of the ball is made to receive the stalk of the large wooden ring, which is seen surmounting it, and which forms the most peculiar feature of the instrument. An iron wire forms the core of this ring, and is in metallic connection with the prime conductor. The function performed by this remarkable appendage is to lengthen the sparks given by the machine. In a 24 in. plate, for instance, with the aid of the ring, the sparks are 14 in. in length, and without it scarcely two. The remaining opening in the prime conductor is for the stalk of the small brass ball from which the sparks are obtained. To the left of the figure is the spark-drawer for receiving the sparks from the machine. The length of the spark given by an electrical machine is by far the most severe test of the excellence of its construction, and, in this respect, Winter's machine is entitled to hold the first rank among friction-machines. A machine 12 in. in diameter costs £5.

Another and most interesting electrical machine, by which the apparent anomaly of frictional electricity *without friction* is realised, was exhibited in the Great French Exhibition of 1867, and described by a careful observer, in the 'Mining Journal.'

"In appearance, Holtz's machine resembles the ordinary plate machine; in fact, the most prominent part is a glass disc, which is mounted and revolved in the usual manner. But the plate is thinner—the thinner the

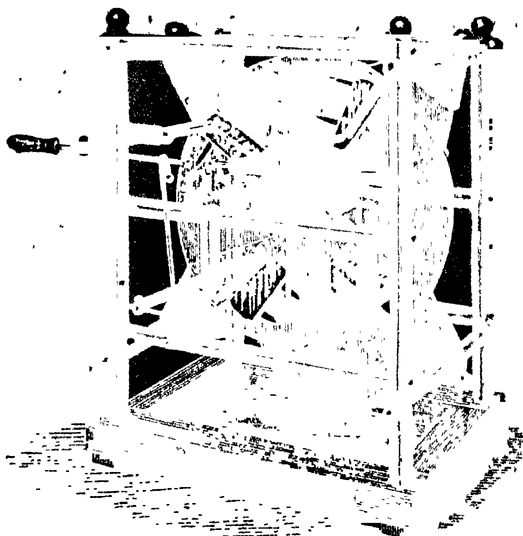


FIG. 202.—*The Holtz Electrical Machine, giving "frictional electricity" without friction.*

better—and as it is desirable to revolve it very rapidly, a multiplying wheel is connected with the plate, so that the speed may be increased to the extent desired. The machine, however, has really but little resemblance to the plate machine, for it has no rubbers; it produces torrents of frictional electricity, but the electricity is not generated by friction; there is no friction about the machine, except at the axle bearings. The plate revolves in free air, and nothing should touch it. In the place of rubbers are what are called inductors, which are strips of paper 3 or 4 in. long, and about 1 in. wide. They are supported and insulated on pieces of glass, which are of spear-head form. The inductor is made complete by pasting on to the paper pointed pieces of cardboard, which project beyond the glass spear-heads an inch or two. The spear-heads are attached to the framework of the machine, so that they shall be parallel, and as near as possible, to the plate on its crank side. Opposite the inductors, at the front of the plate, are the comb points, which serve to collect the electricity, and convey it to the conductors for use. Each inductor is furnished with its set of points. The combs are attached to brass rods, terminated at their other ends by brass balls. The rods are fastened to the framework of the machine, and are insulated from it. The balls at the ends of the rods may be connected to each other in any desired order by means of bent wires.

"To obtain the electricity, one of the inductors is slightly charged, by means of an excited rod of hard rubber, glass tube, or otherwise, and turning the crank. Its power progressively increases for about a minute, and until it reaches the maximum, when it furnishes a steady supply of electricity as long

as the disc is revolved. The amount of electricity which a disc of only 2 ft. in diameter will yield is enormous.

"To explain the action of the machine three elements must be considered —the inductor, the plate, and the comb points. If a pointed wire be brought opposite an electrified body—as, for example, a prime conductor—the positive electricity of the prime conductor attracts the negative of the wire, and repels its positive, and a stream of negative electricity flows out of the wire at its point, while the positive flows to the opposite direction. Now, suppose a sheet of glass be interposed between the point and the conductor. The attraction of the positive electricity of the conductor for the negative of the wire is by no means lessened; the negative is accumulated towards the point, and, by reason of its higher tension, flows out on to the glass. But the glass is impervious to the electricity, and it remains on its surface; the glass becomes electrified. In Professor Holtz's machine we have the electrified body in the inductor, the wire point opposite, and the glass plate interposed. Suppose inductor No. 1 electrified positively, this positive electricity attracts negative electricity out of the comb points on to the interposed plate. The plate moving on the part electrified negatively comes opposite card points of inductor No. 2. Here the negative electricity of the plate draws out of the card points positive electricity on to the glass, and inductor No. 2 becomes charged negatively, while the glass is negatively charged on the further side, and positively charged on the near side. Inductor No. 2, being charged negatively, draws positive electricity out of comb points No. 2, and neutralizes the negative drawn from comb points No. 1. Card points No. 3 discharge negative electricity on the plate, and inductor No. 3 becomes positive, and, like No. 1, draws negative electricity out of the corresponding comb point. It will be seen that the alternate inductors are oppositely electrified, and that their corresponding comb points give out or receive accordingly. By varying the manner of connecting the balls at the extremities of the comb points a considerable variety of changes in the relation of the quantity and intensity may be obtained. These variations are somewhat similar to those which are secured by varying the order of connecting the elements of the galvanic battery. The greatest intensity is obtained by connecting the inductors as they stand in numerical order round the disc. By connecting one of the poles with the ground, the other may be used as a prime conductor for charging Leyden jars, &c. It is found advisable, in order to secure more perfect insulation, to varnish the plate and the inductors with shellac varnish."

ELECTRICAL ATTRACTION AND REPULSION GOVERNED BY CERTAIN LAWS.

The electroscopes already described are merely intended to indicate the development of electricity; their construction does not permit any calculation to be made as to the quantity of the force present in or upon any given surface.

In using a common magnet to attract a needle, it is evident that *distance* regulates the intensity of the power, which increases rapidly as the two are brought in closer proximity, or decreases as quickly by increasing the distance between them.

The influence of distance is particularly shown in experiments with static electricity, and the phenomena were carefully examined by Coulomb, who determined the laws which bear his name.

First Law of Coulomb.—Two electrified bodies attract or repel each other with a force which is inversely proportional to the square of the distance that separates them.

Example: An electrified body at a certain distance exerts a force which may be called unity or one; at half that distance the power is four times greater; at one-third, nine times; one-fourth, sixteen times greater, and so on.

Second Law.—The distance remaining the same, the attractions or repulsions are in the compound ratio to the quantities of electricity which the two bodies possess.

Example: A fixed electrified ball, which will repel another and movable one to a certain distance, called unity or one, will have only half the power if connected with another ball of the same size, the charge distributed over one surface is now spread over double the surface; and if this again is connected with another ball, the force is halved again, and possesses only a quarter of its original power.

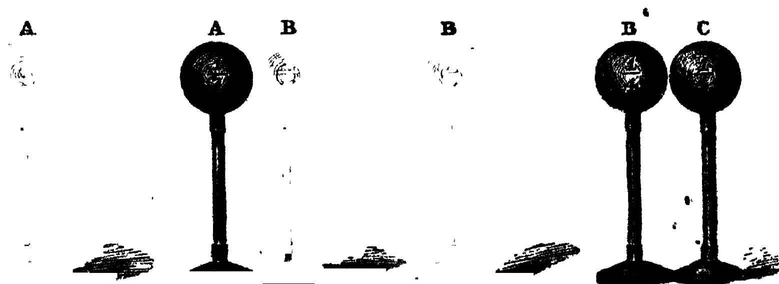


FIG. 203.

A. an insulated ball electrized with a force to be called unity, 1; A B, the same ball touching another ball of the same size, B. The charge is now spread over twice the surface, and the force is reduced one-half. B, the ball with one-half the charge; B C, the same ball touching another, C. The original charge is again spread over twice the surface, and the force reduced at A B to one-half is now reduced at B C to a quarter.

On the same principle, by reversing the previous experiments and increasing the charge, if a series of balls, gradually decreasing in size, are attached to any given-sized ball, they must end in a very small ball, or that to which it is equivalent, viz., a point; consequently the charge increases in intensity, instead of diminishing: and hence the use of points, which discharge electricity very rapidly; or receive it, as in the points attached to the prime conductor of an ordinary electrical machine. The electric force tends to escape from the surface of conductors by virtue of the repulsion of its own particles.

The force it exerts is considered proportional to the square of the quantity; hence, if the accumulation of electricity in eight balls decreasing in size be taken as 1, 2, 3, 4, 5, 6, 7, 8, the force will be the square, as shown in Fig. 204.

The last ball, which is eight times less in area than the first, is charged eight times more than the first, and the force, or desire to escape or polarize the surrounding particles of air, is increased by the square, viz., sixty-four times.

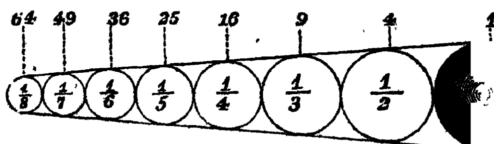


FIG. 204.—*The rationale of a Point, and why it gives off Electricity.*
The lines show how a point is arrived at from a series of spheres gradually decreasing in size.

These laws, and the applications which flow from them, were discovered by Coulomb with the very delicate instrument called the Torsion Electrometer, or Torsion Balance (Fig. 205). It consists of a cylindrical or cubical glass box, carrying upon, but communicating through, the upper pane of glass a vertical tube 15 or 20 in. high. The box may be 12 in. high.

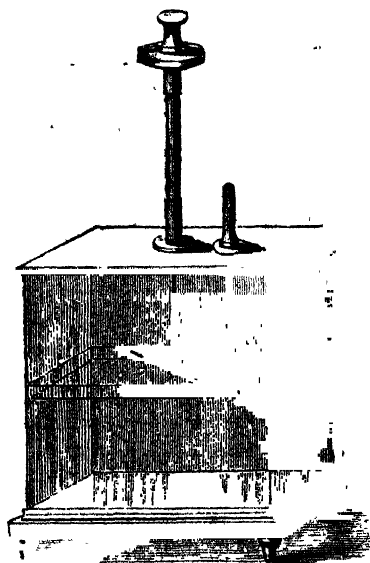


FIG. 205.

At the top of the tube is a graduated circle and pointer, and inside this, and exactly in the centre, is attached a fine silver or platinum wire, stretched by a little weight.

The wire suspended from the top of the tube is long enough to reach to the centre of the box; and through the weight that stretches it is passed a horizontal needle of gum lac or glass. The needle is not suspended like a balance; but one arm is longer than the other, and carries a little disc of gold paper or a small gilt pith-ball.

In order to measure the space traversed by the needle, a proper scale is

placed in the centre of the front glass pane; and, before commencing experiments, the zero of the circle carried by the tube is made to correspond with the zero of the scale in the box; and this can be done by carefully moving round the top scale, to the inside of which is attached the metallic wire carrying the little weight and needle.

The needle is affected by the electricity from a ball or disc of exactly the same size as that attached to the needle, which is supported by an insulating stem. It is introduced vertically in another hole made through the top pane of glass, and the whole is so arranged that, when the ball of the needle is in contact with the other, the needle is in the direction corresponding to the zero or 0° of the two scales.

In the cylindrical glass Coulomb balance the vertical ball is suspended by a metallic rod, which goes through the top, and is attached to another ball. It is not then removed as in the square-box balance; but a "proof plane" on an insulating handle is applied to the electrified body under examination, and this is caused to touch the outer ball of the balance.

In the square-box balance the ball is removed by its insulating handle, and the electrified body under examination is touched with it, and the ball placed inside the box. According to the first law, it immediately divides its electricity with the ball of the needle, which latter, being repelled, describes a larger or smaller arc, according to the intensity of the charge.

Directly the needle is repelled, the wire must be twisted; and this is called the force of torsion. Coulomb ascertained that the forces of torsion are proportional to the angles of torsion; or, in other words, the force that causes the torsion or twisting of the wire is exactly proportional to the arc described by the needle.

Supposing the needle to be repelled to the distance of 36°, in order to compel the needle to come to 18°, the top circle on the tube must be moved round 126 degrees; from which it follows that the wire, if twisted 18° below and 126° above, makes up a torsion equal to 144°. Under the same circumstances, to reduce the arc to 9°, an angle of 576° of torsion must be used. The relation of the 36°, 18°, and 9° are to each other as the angles of torsion, 36°, 144°, 576°, or these angles are to each other as 1 : 4 : 16; hence, if the distances are to each other as $1 : \frac{1}{2} : \frac{1}{4}$, the repulsive forces are to each other as 1 : 4 : 16, and the first law of Coulomb is proved.

The late Sir William Snow Harris employed a delicate brass scale-beam, suspended from a curved brass rod fixed to an insulating support; the beam carried a circular gilded plane from one arm, and the scale from the other; the gilded plane is suspended over another plane of the same size, which can be raised or depressed at pleasure. The attraction between the two planes was estimated by the weights raised, and the instrument is known as Harris's Balance Electrometer (Fig. 206).

It is with these apparatus (the bifilar balance and balance electrometer), and by greatly varying his experiments, says De la Rive, "that Sir W. Harris found that the law of the inverse of the square of the distance is not exactly sustained, except when the balls or the discs are charged with an equal quantity of electricity, when this quantity is not too feeble, and, finally, when the angular distance that separates them is greater than 9°.

"Otherwise, and especially if the electric charges of the two bodies are very different, the force becomes the inverse of the simple distance, within certain limits. The same causes equally modify the second law, which establishes

the relation existing between the quantities of electricity and the attractive or repulsive forces. Thus in one experiment, the respective quantities of electricity being successively on each of two discs in turn 1 and 2, the corresponding repulsive forces, instead of being 1 and 4, were 1 and 5. This deviation from the law was due to the absolute intensity of the electricity being too feeble. But it is much more sensible when there is inequality in the electric charges of two bodies, and when this inequality is very great.

"These numerous exceptions to Coulomb's laws are in a great part due to there occurring to electrised bodies, when in presence of each other, important modifications in their electric state, by the effect of influences whose action we shall study further on—influences which are the more sensible as the electric charges are more different.

"They depend also upon its being very probable that the laws in question are general only for *points* almost *mathematical*, and not for bodies of any forms or dimensions.

"Now we conceive that they must be so when we employ, as Coulomb did, small equal spheres for electrised bodies; for, as is demonstrated in mechanics, the action of a sphere is always the same as that which would be exercised by its centre, supposing all the forces with which the sphere is endowed were concentrated in this centre. We see, therefore, that Coulomb's laws may be regarded as general by restricting them to the cases of electrised molecules or points; and that in other cases they may be regarded as deviating less from the truth as the bodies are of smaller dimensions, and as the forms approach more or less the spherical form."

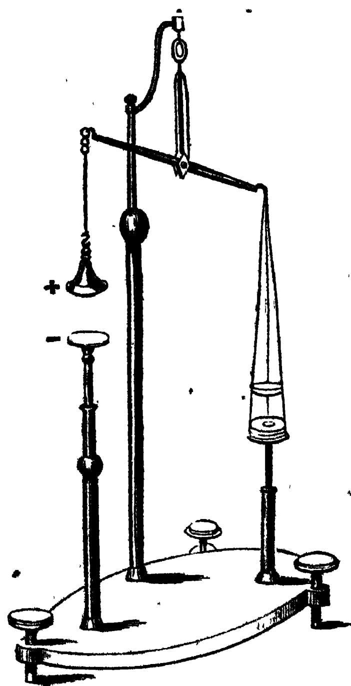


FIG. 206.
Harris's Balance Electrometer.

When a sponge, or any other porous matter, is dipped in water, the latter is taken up by the whole mass, and diffused through it. Similar ideas might be formed with respect to a charge of electricity—that it spreads itself through the whole body of the conductor on which it was rendered evident; this, however, is not the case; *the electricity arranges itself on the surface of electrified bodies.*

Hence balls and cylinders used in the construction of electrical apparatus, such as conductors, are always made hollow: solidity is not necessary. The most conclusive experiment to prove the fact already stated was that made by Coulomb. Having insulated a sphere of metal, it was charged with electricity, and on the application of two hemispheres, supported, of course, by glass rods,

the whole of the charge was removed when they were taken away and applied to an electroscope; whereas the original ball first charged did not exhibit the slightest charge when tested with the same instrument.

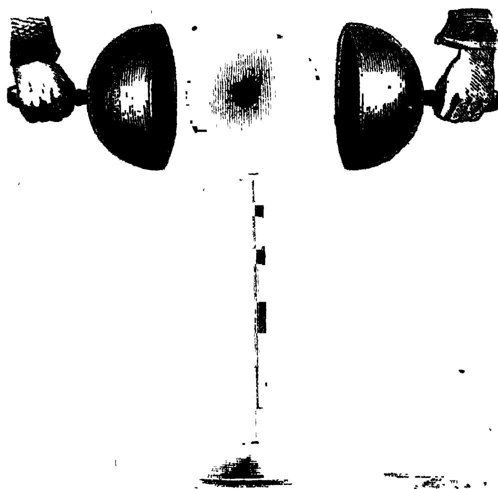


FIG. 207.—*Coulomb's Experiments, showing the distribution of the Electricity on the surface of insulated Conductors.*

The ball being first electrified, and the hemispheres applied, which remove the charge.

Faraday, whose name is so completely identified with the subject of electricity, devised many clever experiments to show the fact.

One of the best is where he uses a conical muslin bag attached to an insulated ring. At the apex of the cone, both outside and inside the net, is a silken thread for the purpose of turning it inside out. When the bag is charged, a "proof plane," *i.e.*, a metallic plate attached to a glass or wax rod, or a small disc of gilt paper fixed to a thin rod of shellac or glass, is placed in the interior, and then applied to a delicate electroscope, which remains unaffected.

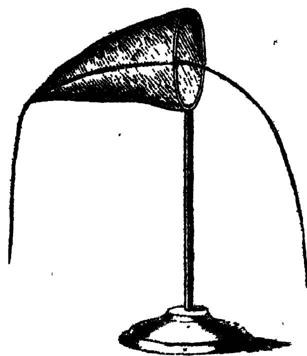


FIG. 208.
Faraday's Experiment with the conical Muslin Bag.

If, however, the proof plane touches the outside of the bag, a charge is obtained, which is rendered evident directly the electroscope is used. By turning the bag inside out (whilst insulated and charged) with the dry silk string, silk being a non-conductor, the condition is reversed; that which was the outside is now the inside, and gives no evidence of electrical excitation, whilst that which was inside is now outside, and, of

course, will deliver a charge to the proof plane. A bird, a white mouse, some gunpowder, and a delicate electroscope, placed inside a wire-gauze cover, such as might be used for protecting meat, standing on a stool with glass legs, and connected with the electrical machine when in full action, will give an abundance of sparks from the outside, which do not affect the living things, the gunpowder, or the electroscope in the slightest degree.

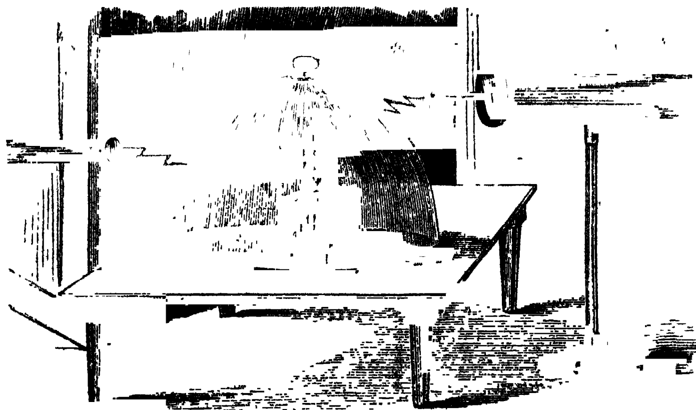


FIG. 209.—*The Mouse, the Bird, Gunpowder, and Electroscope under a Wire Gauze Cover.*

When two gilt pith-balls, hanging side by side, and suspended from an insulating stand, are electrised, they stand out and repel each other, with a force indicated by the distance at which they are separated. The distance is a rough measurer of the intensity or energy of the charge.

By attaching the pith-balls to an insulated cylinder (Fig. 210), round which a riband is wound up close, and conveying a charge from the electrical machine, they repel each other for some time, and remain in that state in dry and moderately warm air. If, however, the flap or riband of silk is unwound by the glass handle, the electricity is spread over a larger surface, the intensity of the original charge is diminished, and this is shown by the pith-balls falling together, and again returning to their original distance, or nearly so, when the glass is again wound up.

This experiment is quite in accordance with the laws of Coulomb, already explained at page 228. Instead of the proof plane, a "carrier ball," as Faraday termed it, may be used; this is made of some nicely turned light wood, covered with gold paper, and supported by a silk thread, well dried, and saturated with shellac. The latter is easily dissolved in methylated spirit, by digestion in the cold for a day or so. Of course, warming the spirit by putting the bottle on a piece of wood standing on the hob of a grate will accelerate the solution; but care must be taken to avoid the chance of its taking fire. Most of the above experiments were devised by Faraday; but it is easily shown that the principle of distribution and the proof that electricity resides

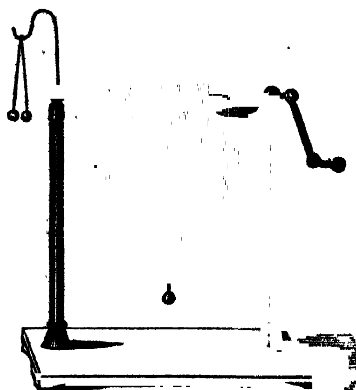


FIG. 210.—*The Cylinder charged, and the flap unwound.*

on the surfaces of metallic electrified bodies was well known and shown by Cavallo in his book published in 1777. The experiment quoted is called

THE ELECTRIC WELL.

"Place upon an electric stool a metal quart mug, or some other conducting body nearly of the same form and dimension; then tie a short cork-ball electrometer at the end of a silk thread proceeding from the ceiling of the room, or from any other proper support, so that the electroscope may be suspended within the mug, *and no part of it may be above the mouth;* this done, electrify the mug by giving it a spark with an excited electric, or otherwise, and you will see that the electroscope, whilst it remains in that insulated situation, even if it be made to touch the sides of the mug, is not attracted by it, nor does it acquire any electricity; but if, whilst it stands suspended within the mug, a conductor, *standing out of the mug*, be made to communicate with or only presented to it, then the electroscope acquires an electricity contrary to that of the mug, and a quantity of it which is proportionable to the body with which it has been made to communicate; and it is then immediately attracted by the mug. Cavallo explains the cause in his own quaint language, and his theory is in accordance with that taught in these days, only the technical names are changed; thus, in modern style, the fact would be explained by stating that "polarity cannot be set up when opposing actions are at work in different directions, as in the inside of an insulated metallic vessel." Cavallo says, "The reason why, in this experiment, the electroscope contracts no electricity whilst suspended entirely within the cavity of the mug is because the electricity of the mug acts upon the electroscope *on all sides*, and this has no opportunity of *parting* with its fluid when the mug is electrified positively, nor of *receiving* any when the mug is electrified negatively. But, as soon as any conductor communicates with it, the electroscope becomes immediately *possessed* of the electricity *contrary* to that of the mug; for, if the mug be electrified positively, the fluid belonging to the electroscope will be repelled to that body which communicates with it, and which, being out

of the mug, cannot be affected by its electricity; and if the mug is electrified negatively, it will attract the fluid of the electroscope, which actually receives an additional quantity of it from that conducting body with which it communicates.

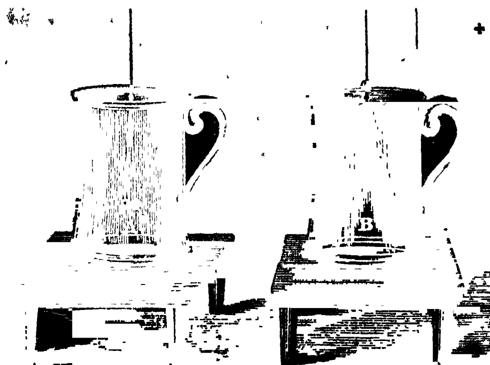


FIG. 211.—*Cavallo's Electric Well.*

A, quart mug insulated, and containing the electroscope *inside*; B, the threads raised above the edge of the vessel, or, still better, touched with an insulated brass rod extending into the air. In A, opposing forces, + and +, oppose in different directions In B, polarity can be set up; because the inside is +, the electroscope —, and the extremity of the rod in the air +.

"The electroscope, therefore, becoming always possessed of a contrary electricity, must necessarily be attracted.

"If, by raising the silk thread a little, part of the electroscope, *i.e.*, of its linen threads, are lifted just above the mouth of the mug, the balls will be immediately attracted; for then, by the action of the electricity of the mug, it will acquire a contrary electricity *by giving to* or *receiving* the electric fluid from *the air* above *the cavity of the mug.*

"It has been supposed by some that the electroscope in the above experiment (or any other small insulated body), hanging in the cavity of an electrified vessel, or the like, is not attracted by the sides of the vessel because the attraction of electricity, *being as the squares of the distances inversely*, cannot affect the electroscope one way more than another; it being demonstrable that if to every point of a spherical concave surface equal centripetal forces are directed, decreasing as the squares of the distances from those points, a small body situated anywhere within that surface would remain there without being attracted one way more than another.* But to this it may be replied that the demonstration of the above-mentioned proposition, if it is applicable to spherical or cylindrical concave surfaces, cannot, however, be applied to every kind of irregular cavities, with which, if they exceed not a certain size, the above experiment succeeds as well as with the cylindrical cavity of the mug."

Cavallo proceeds to give what he considers to be the proper theory, which in the main is right; but, as before observed, the explanation is simplified by stating that, as polarity cannot be set up inside a vessel, so a charge cannot be maintained.

* Newton's "Principia," Book I., prop. lxx.

ELECTRICAL INDUCTION.

In studying the phenomena of light and heat, it will be necessarily observed that these forces have a radiant power. A heated body may be brought towards another which is not heated, and impart to it a certain amount of its warmth; the latter gains what the former loses: the vibratory power set up in the heated body is supposed to be conveyed by the undulations of the ether to the body which is not heated, and setting up therein similar vibrations; the result is that heat is produced in a cold substance by the approach of a heated body, which loses its vibrating energy in warming the other.

Loss of power, independent of any conducting power of damp air, curious to say, is not observed when an electrified body is gradually brought towards another which is not electrified; and yet the electrical quiescence of the latter is disturbed, and may give rise to large quantities of electricity, as in Holtz's electrical machine (Fig. 202); the effect thus obtained is called "induced electricity."

The fact is well shown by using a cylindrical conductor, the two halves of which can be separated with their respective insulating glass columns. On the underside of the conductor small rings or hooks may be inserted for the convenience of attaching pairs of gilt pith-balls, which should be as light as possible.

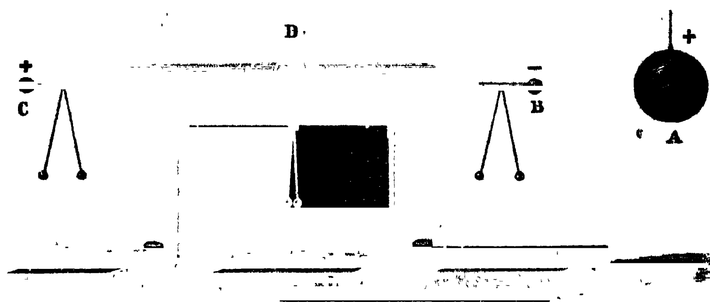


FIG. 212.

A, the electrified ball approached to the conductor, B C, made in two halves to separate at D; each half to have one suspended pith-ball at D, so that, when joined together, they form a pair of balls as in the ordinary electroscope; also each to have a pair at the extremities B and C.

Directly the charged ball A has approached sufficiently near to the conductor B C, the pith-balls show by their mutual repulsion that its electrical quiescence is disturbed, and that, in fact, if the ball has been charged with positive or + electricity, it will cause negative or — electricity to become apparent at B, whilst positive or + electricity will be found at C. The pith-balls hanging at D will hardly be disturbed, if at all, showing that there is a neutral point, like the centre of a bar magnet, where the forces are balanced. When the disturbing cause A is removed, the separated electricities rush together again, the electrical equilibrium of the cylinder is restored, and the pith-balls no longer repel each other.

No advantage, therefore, so far as the production of a permanent charge of electricity, has been obtained in the above experiment, which, it must be remembered, is performed with a conductor of electricity. If, however, the experiment is repeated, and, whilst the conductor is under induction from the ball A, the two halves are separated, then it will be found that each half is permanently electrified.

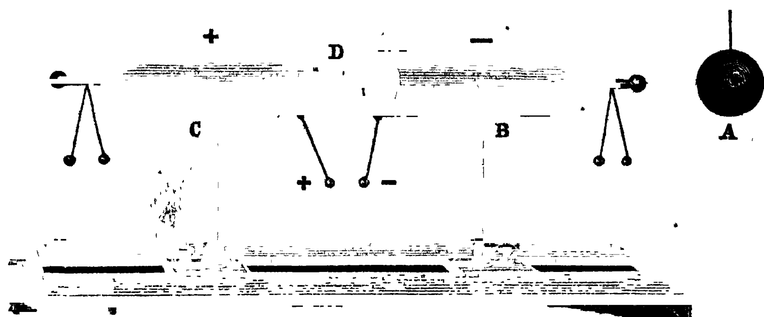


FIG. 213.

A, the electrified ball; B, the half of the cylinder, separated from the other, and showing a charge of negative or — electricity; C, the other half, showing positive or + electricity; D, the single balls, suspended from B and C, attract each other, as they represent the opposite electricities, + and —.

The separation of the halves of the conductor *whilst under induction* has prevented the opposite forces reuniting; the pith-balls remain deflected on each half, and the single balls, suspended at the place where the two halves are separated, incline towards each other, because dissimilar electricities attract. The equality of the electrical disturbance is again beautifully shown by bringing the halves together, when the electrical excitation set up entirely ceases, as the two opposite forces exactly neutralize each other.

The experiment may be once more repeated, and the two halves separated whilst under induction. If a stick of excited wax is approached to the half of the cylinder marked B, minus, the pith-balls are deflected still further from each other; but when the same stick of excited sealing-wax is brought towards C, or plus electricity, the balls drop down.

In the first case, the increased deflection shows that the electricity on B is negative, because the wax is negative, and exalts the previous charge. In the second, the diminished deflection and falling down of the balls show that the electricity on C is positive, as it is neutralized for the time being by the influence of the negatively electrified wax.

Two electroscopes, one placed in connexion with each half of the conductor, may be substituted for the pith-balls, and are, perhaps, more certain and truthful in their indications; moreover, they are more delicate, and would show a smaller amount of electrical disturbance.

These experiments demonstrate that, in conductors, *polarity*, *i.e.*, the separation of the electricities, the production of opposite properties in opposite direction, may be set up by induction, but *is not maintained;* and this is, in fact, as contended by Faraday, the essential difference between conductors and non-conductors: in the former polarity is not maintained; in the latter, as we shall

now see, polarity, being set up, is maintained, or it would be impossible to charge a Leyden jar.

When a plate of glass is held against the ball attached to the prime conductor of an electrical-machine, and a pith-ball, suspended on a glass support, is approached towards it, the ball is energetically attracted towards the glass; and yet the latter, being called a non-conductor, ought not to have permitted the electricity to have apparently travelled, like heat, through its substance.



FIG. 214.

A, one side of the glass plate, which may be one foot square, and is held against the ball of the electrified conductor; B, the ball suspended on the glass stand, and attracted to the other side of the glass plate.

The electricity does not travel through the glass plate, but, like the brass conductor (Fig. 212), is thrown into an electro-polar state, the one side touching the conductor being positive, and the other side, to which the pith-ball is attracted, being negative; a very slight charge is thus conferred upon the glass plate, which will not rise higher until one side is put in conducting communication with the ground. The small charge, however, is retained when the glass is removed, and thus the polarity is shown to be *maintained by non-conductors*, constituting the essential difference between them and conductors of electricity.

The sheet of glass cannot be charged properly unless both surfaces are

coated with tinfoil, within, say, 2 in. of the outer edge. On a sheet of glass 1 ft. square, the tinfoil will be 8 in. square. If this plate is supported on an insulating stand, by being placed in the cleft or groove of a piece of mahogany fitted on the top of a glass rod, fixed in a proper foot, the charge, as before stated, is very slight, because the force called positive electricity applied to one side of the plate, which may polarize the particles of the glass, is opposed by the positive electricity resident on the other side of the glass, and a balance is arrived at—a dead lock; the particles cannot increase their charge, because the order is broken, and instead of the continuity being represented by Fig. 215, where + is at one end and — at the other, the regu-

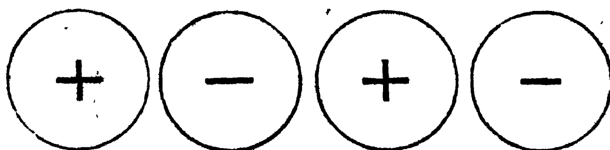


FIG. 215.

larity is destroyed by the last particle being + instead of —, as shown at Fig. 216; and the molecules are now + at one end and + at the other, and must therefore oppose (and thwart, as it were) each other.

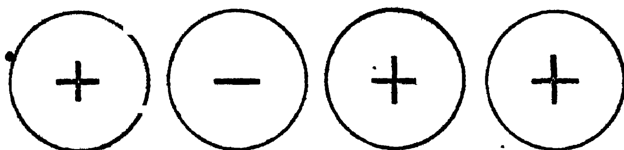


FIG. 216.

The difficulty is, however, overcome by connecting one side of the plate with the earth, when the order shown in Fig. 215 is restored, and the + electricity is said to escape to the ground, which latter, in its turn, represents a vast series of particles all polarized *ad infinitum*, but decreasing in intensity as the distance from the disturbing source is increased, according to the law already explained at page 228.

Faraday insisted that electrical induction was an action of contiguous particles, whether it took place through a metal, or glass, or air; he opposed the "emission" theory of electricity, as others had done before with respect to the emissive theories of light and heat.

Formerly it was supposed that electricity travelled through air without affecting the particles of the air; it was imagined to be a subtle form of matter of its own kind. Faraday laboured to prove that every particle of air becomes polar, and takes part in the propagation of the force, just as the particles of the glass become polar when charged with electricity.

A thin leaf of gold may be + on one side and — on the other, so long as it is subjected to the inductive action of an electrified body brought near it;

that which occurs in a large conductor, as shown in Fig. 212, may occur, microscopically, as it were, in a gold leaf.

If once the student grasps the idea of the polarity of each minute and contiguous particle, the difficulties of Faraday's inductive theory vanish. It is well, here, to dwell on the condition of the surfaces of a glass plate whilst under induction, and receiving a charge of electricity. The late Professor Daniell's diagrams are very excellent.*

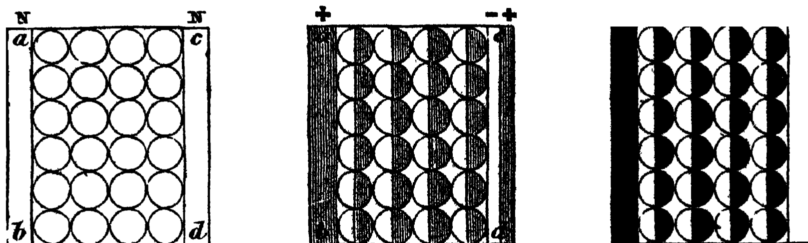


FIG. 217.—*Daniell's Diagram*,

Explaining the condition of the surfaces of an insulated and non-insulated plate of glass, coated with tinfoil.

"Upon the molecular hypothesis of induction, No. 1 may represent a plate of glass with its metallic coatings, *a b* and *c d*, in its neutral state. In No. 2, we suppose the same plate, with its metallic coating, *a b*, in contact with the charged conductor of an electrical machine. Its other coatings we also suppose to be insulated; and, as we know, the plate cannot be charged. The coating *a b*, however, being positive or +, not only will the particles of the glass be thrown into a polar state, but the coating *c d* will also be polar, + —, by induction to surrounding objects; but the charge will not rise to any degree of intensity, because the + electricity of the latter cannot be carried off, or diffuse itself upon the earth, but will react upon the glass. But if we uninsulate this coating, then will No. 3 represent the high state of tension (charge) which the forces will assume under the inductive process, when a high charge of + electricity upon *a b* will sustain an equal charge of — electricity upon *d c* by the polar arrangement of the particles of the interposed dielectric (glass).

"In the above diagrams the unshaded circle represents the particles of glass in a state of electrical quiescence; the shaded circles represent polarity, the shaded half being supposed to be + (plus), the unshaded half — (minus) electricity."

When explaining the cause of electricity residing on the surface of an insulated conductor, it was stated that the interior of the vessel (Fig. 211) was not found to give the slightest charge to the proof plane, because polarity could not be set up properly in consequence of opposing forces in different directions: we may trace out the latter in the next diagram (Fig. 218). Suppose a set of molecules in a polar state starting from A are met by another column of particles in the opposite direction B, which virtually undo all that might have

* Daniell's "Introduction to Chemical Philosophy."

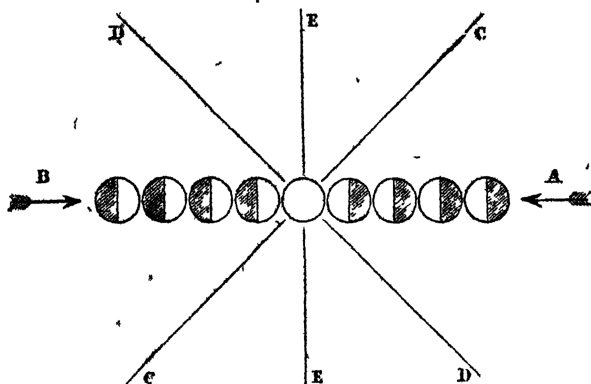


FIG. 218.

...... the polar state cannot be set up in the carrier-ball, or, in ...ct, in the particles of air contained in the vessel under examination by the ...arrier-ball or proof plane.

The same reasoning applies to all sets of molecules coming in the direction ... as opposed to C, D as opposed to D, E as opposed to E.

The nomenclature of the phenomena of ...duced electricity is thus expressed by Fa...aday:

1. The excited body, glass or wax, is called ...e *inductric* or *inductive* body.

2. The effect of the inductric on a distant ...ody, and where no loss of electricity is sus...ined, as by contact, is called *induction*.

3. The electricity thus obtained is called ...*duced* electricity.

4. The body subjected to the action of the ...ductric is called the *inducteous* body.

5. The medium, such as air, through ...hich the electric may act upon the induc...ous body is termed the *dielectric* (δια, ...rough, and ηλεκτρον, electricity). A di...ectric may be solid, fluid, or gaseous.

When the above principles are once com...ehended, it is easy to conceive that every ...nd of electrical attraction must be pre...ded by induction; to demonstrate this ...t, Harris attached a gold leaf to a disc of paper, neatly fixed on a filament of shel... and suspended by a silk thread. The ... may be attached to one end of a well-...d straw suspended by a thread; a little ...f tinfoil on the other end will balance

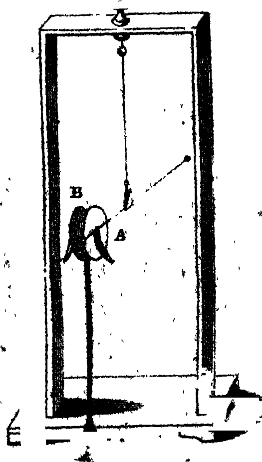


FIG. 219.—*Sir William Snow Harris's Experiment demonstrating that Attraction is p... eded by Induction.*

A, the suspend d disc, with the gold leaf attached, and repelled when B, the electrified disc, is approached towards it.

the gilt disc. Directly another disc electrified is brought towards the suspended disc, the little gold leaf on the other side stands out and is repelled, showing distinctly that the opposite kind of electricity to that which is the disturbing cause must be eliminated, or the gold leaf would not move until the suspended disc *touched* the electrified disc.

At page 211, whilst explaining the construction of the electroscope, it was stated that the instrument could be made more delicate by the introduction of a simple arrangement, through which inductive action is brought to bear upon the cap, and through that to the gold leaves. The part attached to the electroscope-stand is called the *condenser*, and assists in increasing any minute evolution of electricity that would otherwise be insufficient to overcome the weight of the gold leaves, and cause them to repel each other.

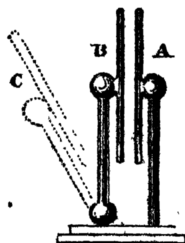


FIG. 220.—*The Electrical Condenser.*

A, plate supported on glass stem; B, plate on a conducting stem, jointed at bottom so as to move to any position C.

It (Fig. 220) consists of two circular brass plates, one supported by a glass insulating stem, and the other resting upon a conducting stem jointed at the bottom. When the plate on the insulated stem is connected by means of a wire with the cap of the electroscope, which may be very feebly excited, as with the pressure of Iceland spar, on the removal of the uninsulated plate, the gold leaves of the electroscope indicate the minute electrical disturbance.

It is evident that between the two plates there must be a dielectric air, the particles of which we have already seen are capable of assuming the electro-polar state.

The electricity from the tourmaline on the cap of the electroscope has charged the insulated plate A, Fig. 220; this throws the intervening air into a polar state, so that the air is in the same condition as the glass plate with its coatings of tinfoil, the latter being represented in this apparatus by the two brass plates. If both plates were insulated, there would be opposing forces, as shown at p. 239; but one, plate B, is connected with the earth. At first, and whilst the plates are near each other, the electricity is said to be *disguised*. All this time, if the electricity on the cap of the electroscope is positive (+), it has, by induction through the film of air, thrown the second plate into the opposite condition, negative or —.

The two electricities on the two plates are, as it were, engaged to each other; the desire to unite, or their tendency towards one another, is simply arrested by the intervening air, and this for the time *disguises* the electrical energy which really exists; but when the second plate is removed, and the two electricities are separated, then it is found that the feeble original charge has been

exalted; for, as the feeble charge from the cap, connected with the insulated brass plate, acted on the other uninsulated brass plate, the latter, by connection with the earth, like the outside of a Leyden jar, reacts upon the insulated plate; so that, when the two are separated, a greater electrical effect is perceptible. By the repeated application of the pressed Iceland spar, and the withdrawal and return of the plate B to A, the charge is virtually increased or *condensed* on A. The closer the two plates can be brought together, the better the effect; but, as the particles of air are soon broken through by a disruptive discharge in the shape of a spark, and particularly so if the air is at all humid, it is found better, as in Volta's condenser, to use a thin plate of some non-conducting material, such as shellac, instead of air. The *disguise* of the two electricities is the more complete when the metallic discs are brought very close to each other, because the attraction of the two electricities becomes stronger as the distance is diminished. The inductive power of the electrified plate must be increased, and the reactionary force of the second plate, connected with the earth, also rises to a more exalted state.

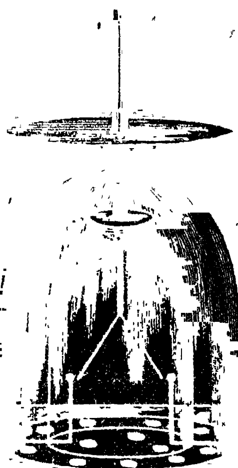


FIG. 221.—*The Gold-Leaf Condenser*

Is so called because it is adapted to a gold-leaf electroscope. The nicety of manipulation required in order to use the instrument properly is described by M. de la Rive, in his "Treatise on Electricity," translated by Mr. Charles V. Walker:

"It is composed of two metal plates, nicely adjusted, of not less than 6 in. nor more than 1 ft. in diameter. On of these plates is screwed on the exterior extension of the metal stem of the electroscope by which the gold leaves are supported, and has a wire and ball attached to it, A; the other, B, is provided with an insulating handle, C, fixed vertically at its centre, and is placed upon the former so as exactly to cover it.

"The two plates have been coated on their surfaces in contact with *several layers*, successively applied, of a very liquid varnish, formed of a solution of shellac in alcohol. This varnish, in drying, forms a pellicle whose thickness does not exceed 1-250th part of an inch, but which is sufficient to prevent the recomposition of the electricities when they are not very strong.

"The plates are thus almost in contact, and the *disguise* of the electricity is as complete as possible; and the condensing power of this apparatus is very considerable; *but it can only support very feeble charges*, which, indeed, are all it is intended to receive. It is important that the two plates be fitted to each other as accurately as possible, and, consequently, that their surfaces be very even. For this reason there is a limit to the size of these surfaces that cannot possibly be exceeded, because their construction would become too difficult, in consequence of the conditions we have pointed out. The manipulation also would be very troublesome; for it is essential that we should be able to raise the upper plate easily, and should take care to raise it perpendicularly, without exercising any *friction* against the other, which of itself would be a source of electricity, and would consequently interfere with the results.

"This reservation being once made, it is advantageous to have the largest possible surface, because the quantity of electricity accumulated is proportional to this surface.

"Experiment has demonstrated that we cannot exceed a foot in diameter, without falling into the inconveniences that we have just pointed out. The plates are generally of brass, and, if possible, of gilt brass, so as to be protected against the chemical action of the moist air, and of the vapours and liquids with which they may have occasion to come in contact.

"Electrical signs are sometimes found on separating the two plates, even although there may be no electrical source in communication with either of them. This error is due to a small quantity of electricity arising from preceding experiments, which has penetrated into the layers of varnish, and which is not got rid of without some difficulty.

"In order to remove it, we must place a very thin sheet of tinfoil between the two discs, and leave it there until we have satisfied ourselves that, after having been placed in immediate contact with each other, the plates liberate no trace of electricity by the mere fact of their separation. It is essential always to determine this absence of spontaneous electrical signs before making an experiment.

"For greater convenience, the source of electricity is generally placed in communication with the upper plate of the condenser B, which is termed the *collector;* and the lower plate, or its connected brass ball, is *touched with the finger.*

"When the two plates are separated, it is the electricity of the lower plate, now become free, that affects the electroscope; but we must not lose sight of the fact of its being of a contrary nature to that of the upper one, and, consequently, to that of the source subjected to experiment.

"Before beginning a second experiment, we must not forget to discharge both the plates by touching them with the fingers; and generally we must never leave them charged, especially when they are in contact, because the electricity that they retain penetrates into the layers of varnish, from which, as we have seen, it is a very difficult matter to expel it.

"By the assistance of this instrument Volta succeeded in showing that a plate of zinc, when held in the hand and put into contact with the upper plate,

charged it with negative electricity—an experiment that was the origin of the voltaic pile. When this experiment is made, care must be taken that the zinc plate be well cleansed, especially in the points where it touches the disc.

"In like manner, we can charge the plate with positive electricity by interposing between the plate and the zinc plate, which is still held in the hand, a disc of cloth or paper slightly moistened with salt water. In each case we must not neglect to touch the lower plate with one of the hands, whilst the zinc plate is held by the other in contact with the upper plate. The experiments that we have just quoted, and the other delicate experiments in which the condenser is used, require the air of the room in which the operation is carried on to be as dry as possible, or at least the electroscope and all the pieces of which it is constructed to be well protected from moisture. With this view, the whole is covered with a glass cage, in the interior of which chloride of calcium is placed, in order to produce the dryness."

Space does not permit us to describe Peclet's instrument, which is still more sensitive, but requires precautions to be taken in its use that almost negative its other valuable qualities.

If the condenser cannot be understood, the youthful student is supplied with fresh ideas, which will help him to do so, in the old-fashioned and most useful instrument, called the

ELECTROPHORUS (ηλεκτρον, *electricity; φορος, carrying*).

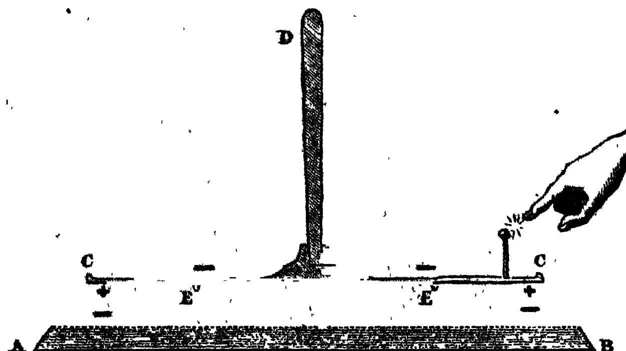


FIG. 222.—*The Electrophorus.*

A B, the tin dish, with the sides sloping inwards, so that the composition cannot fall out; C C, the upper metallic plate and glass handle, D; E E, two spots of sealing-wax, dropped and melted on to the lower side of the metallic plate, to keep it opposed to, but not touching, the resinous plate.

This instrument is spoken of by Cavallo as "a machine for exhibiting *perpetual* electricity;" though he explains afterwards that, being only an excited electric, it must gradually lose its power like all other excited electrics, but being flat it is not exposed to currents of air which may circulate around a stick of sealing-wax, and carry off the charge more quickly.

To make an electrophorus, a circular tin, with a rim ⅜ in. deep, may be provided, about 1 ft. in diameter, and into this, whilst warm, should be poured a mixture of two parts of shellac and one part of Venice turpentine, after they are carefully melted and well incorporated together. When cold, the surface

has a bright polish, and is, of course, remarkably smooth; indeed, care should be taken not to scratch it. The second part of the apparatus—for it consists only of two parts—is the circular flat plate, 10 in. in diameter, made of tin, or gilt copper, or cardboard covered with tinfoil, in the centre of which is a glass rod so fixed that it will lift the metallic plate.

The instrument is charged by gently rubbing or striking the resinous plate with a cat's skin or a warm piece of flannel, and, like the charged pane of glass, described at page 238, the thinner the resinous plate can be cast, the better, as after being rubbed, and always supposing the tin dish is in conducting communication with the earth, it acquires a charge like the Leyden jar, to be described presently. The electro-polar plate having been set up in the resinous plate, the metallic plate with the glass handle (which, in common with all the glass supports of electrical apparatus, should be varnished with shellac varnish) is brought down upon the excited resinous plate; no direct transfer of electricity takes place except when the plate happens to touch the excited wax, and this is prevented, in a great measure, by the two little studs of sealing-wax, E E, already spoken of in Fig. 222.

When the plate is in position, and held by the glass handle, the two electricities, positive and negative, naturally resident in the metal, separate, as already described in the explanation of the phenomena of induction, at page 237; because induction may not only take place in a long conductor, but on the opposite sides of a tin, copper, or other metallic plate.

If the plate is now removed and examined, it is not found to have acquired any charge of electricity; *conductors do not retain polarity;* and the two forces, separated whilst the metallic plate was in the neighbourhood of the excited resinous plate, come together again, as already described fully at page 236.

The metal plate is again laid upon the lower excited resinous plate, and now, if touched by the finger just the moment before it is raised by the glass handle—for the act of touching and raising should be almost simultaneous, and is soon learnt with a little practice—then, on applying the knuckle to the edge of the metallic plate or to the brass ball, a spark immediately passes; and thus, by continually touching, raising, and applying the top metallic plate by its glass handle to a small Leyden jar, the latter is speedily charged.

The *rationale* of the necessity for touching is easily explained. When the plate is under induction, the lower side facing the negatively electrified resinous plate is positive, and the upper side negative; on touching the plate, positive electricity passes to the negative, and the upper surface receives a charge in excess of its natural quantity, and, instead of the two sides being represented by +, plus, and —, minus, the plate, when removed, is found to be + — +. Here is an excess of electricity, which passes to the knuckle in the form of a spark, and again restores the equilibrium to + and —.

It is in this way that the metallic plate can be charged any number of times by alternately touching and raising, and the resinous plate loses no electrical power whatever.

Holtz's electrical machine, described at p. 226, is another and very notable instance of the same kind.

If the resinous plate in its tin dish, before being rubbed, is placed on an insulating stand, so as to be well insulated, and is then rubbed, care being taken not to touch the metallic dish, it acquires little or no charge. The under side of the resinous plate must be in conducting communication with the ground, like the glass plate with the tinfoil coatings, described at p. 239.

When the whole apparatus, previously excited and ready for use, is placed on the insulating stand, and the metallic plate raised, it acquires so slight a charge that it will not give a spark, and would only affect an electroscope, which, Cavallo says, "shows that the electricity of this resinous plate will not be conspicuous on one side of it, if the opposite side is not at liberty to part with or acquire more of the electric fluid."

The original electrophorus invented by Volta was a circular glass plate, covered with a composition made of equal parts of shellac, rosin, and sulphur; and these plates, no doubt, from their thinness, would answer the purpose remarkably well.

Cavallo, who is always so thoroughly practical in his electrical experiments,

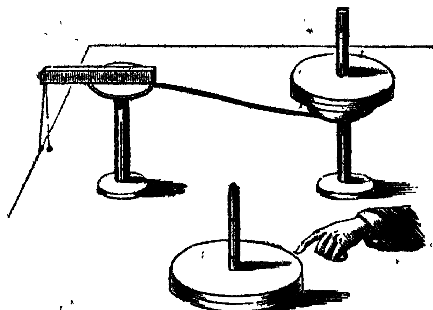


FIG. 223.—*Electrophorus, made of Glass, and covered with Sealing-wax.*

says that he made one of a glass plate, and no more than 6 in. in diameter: when once excited, it could charge a coated Leyden phial several times successively, so strong as to pierce a hole through a card with the discharge. Sometimes the metal plate, when separated from it, was so strongly electrified that it darted strong flashes to the table upon which the electric plate was laid, and even into the air, besides causing the sensation of the spider's web upon the face brought near it, like an electric strongly excited.

"The power of some of my plates" (which he covered with sealing-wax, second quality), he says, "is so strong, that sometimes the electric plate adheres to the metal, when this is lifted up; nor will they separate, even if the metal plate is touched with the finger or other conductor."

Thus, with a circular piece of window-glass, covered with sealing-wax melted on to it, a circular piece of wood or card covered on both sides with tinfoil, and fixed by a pasteboard tube to a glass rod, a very serviceable and cheap electrical machine can be made by young people.

The Leyden jar is nothing more than the coated glass pane (p. 238) rolled up or made into a cylinder.

It was discovered by three philosophers, who were working together at Leyden, viz., Muschenbroeck, Allaman, and Cuneus. They were attempting to collect and store electricity in a bottle, containing some water, through the cork of which was thrust a nail, touching the water; the first shock was received when Muschenbroeck, holding the bottle in one hand, touched the nail with the other accidentally. One smiles, thinking of personal experience in

these matters, to imagine the half-frightened wonderment of the worthy sage, who might have supposed that he had invoked the demon or "genius," good or evil, of the bottle.

Of course, everybody throughout Europe was made acquainted with the electric shock by travelling electricians, who, like the travelling "ghost" show-men of the present day, relieved Muschenbroeck of any trouble in communicating his discovery to the world in general.

As the water was found to be inconvenient, in consequence of the vapour condensing in the upper part of the bottle, and thus reducing the distance between the outer and inner surface of glass, so that a small charge only could be obtained, brass filings, fixed on with some varnish, were next tried; and Cavallo devotes more than a page of his "Complete Treatise on Electricity"

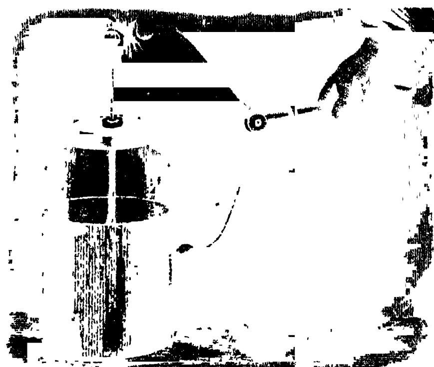


FIG. 224.—*The Leyden Jar and Discharger.*

to the narrative of a grand explosion and smoke arising from the interior of his Leyden bottle, prepared with varnish and brass filings, in consequence of the latter taking fire with the electric spark, which, darting from point to point of the filings, set the inflammable mixture of air and spirit vapour from the varnish on fire; and he adds, regretfully, that, after it had burnt out, all the brass filings fell to the bottom of the bottle, because the adhesive quality of the varnish was destroyed by fire.

The older electricians sometimes used mercury instead of water; but this was soon found to be very expensive, and not applicable to large jars, in consequence of the great weight of the metal.

The principle of the Leyden jar being once understood, viz., that the water accidently used by Muschenbroeck in his bottle was the inner conducting coating that conveyed the electricity to all parts of the interior surface of the glass, and that the undesigned application of the hands on the outside served for the outer coating, a little more consideration brought electricians to the use of tinfoil, no doubt suggested by the use of this metal in the art of silvering looking-glasses.

There are no better directions for coating and preparing Leyden jars and batteries than those given by Cavallo, who says, "When glass plates or jars,

having a sufficiently large opening, are to be coated, the best method is to coat them with tinfoil on both sides, which may be fixed upon the glass with varnish, gum-water, paste, beeswax, &c.; but in case the jars have not an aperture large enough to admit the tinfoil, or an instrument to adapt it to the surface of the glass, then brass filings, such as are sold by the pin-makers, may be advantageously used, and they may be stuck with gum-water, bees-wax, &c.; ***but not with varnish***, for this is apt to be set on fire by the discharge. Care must be taken that the coatings do not come very near the mouth of the jar, for that will cause the jar to discharge itself (now called a *spontaneous discharge*.

"If the coating is about two inches below the top, it will in general do very well; but there are some kinds of glass, especially tinged glass, that, when coated and charged, have the property of discharging themselves more easily than others, even when the coating is five or six inches below the edge.

"There is another sort of glass, like that of which Florence flasks are made, which, on account of some unvitrified particles in its substance, is not capable of holding the least charge. On these accounts, therefore, whenever a great number of jars are to be chosen for a large battery, it is advisable to try some of them first, so that their quality and power may be ascertained.

"If a battery is required of no very great power, as containing about eight or nine square feet of coated glass, I should recommend to make use of common pint or half-pint phials, such as apothecaries use. They may be easily coated with tinfoil, sheet lead, or gilt paper on the outside, and brass filings on the inside. They occupy a small space, and, on account of their *thinness*, hold a very *good charge*; but when a large battery is required, then these phials cannot be used, for they break very easily, and for that purpose cylindrical glass jars of about fifteen inches high, and four or five inches in diameter, are the most convenient."

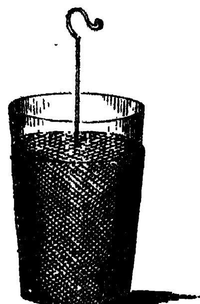


FIG. 225.—*Leyden Jar with shifting coatings.*

It is easily shown, by charging a Leyden jar fitted with shifting coatings, made of light tin-work or of wire gauze, that they have nothing to do with the maintenance of the charge; they simply act as channels for the conveyance of the electricity to all parts of the glass. It is the polarity of the particles of the glass, which is kept up as long as the jar is charged, and is only destroyed when the interior of the jar is brought in conducting communication with the exterior by means of the useful instrument called the discharger, already shown in Fig. 224.

The Leyden jar with shifting coatings, having been charged, is discharged with a loud snapping noise, by bringing one ball of the discharger to the outside, and the other to the ball coming from the inside.

The jar is again charged, and the arm of the discharger is used to take out the interior coating. Directly that is removed, the jar may be lifted out of its outer coating, and, if the air of the room is dry, may be left some time without fear of its losing the charge. The charged Leyden jar would keep its electrical polarity still longer, if put under a dry glass shade, as the air around the Leyden jar would then remain still, and would thus retard the slow discharging of a charged glass surface, when the air of the room is in constant motion, by

reason of the warmth of the fire, or the movements of persons about the room who are engaged in making the experiments.

After waiting a reasonable time, the jar may be lifted into its outer coating, and the inner one can be quickly and dexterously returned, by the assistance of the discharger, to the interior; and now, on applying the discharger as before, a loud cracking and brilliant spark prove that the charge was confined to the particles of the glass.

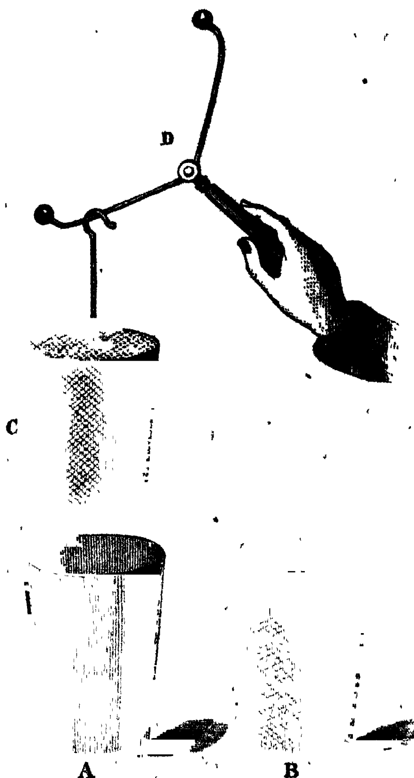


FIG. 226.

A, the conical glass jar; B, the outer coating; C, the inner coating; D, the discharger.

An insulated Leyden jar, like the coated pane described (page 238), cannot sustain a charge. Franklin soon discovered this fact, and hence the experiment is usually called "Franklin's experiment with the Leyden jar."

The jar may be supported on a stand with a long glass support, which of course must be dry, and insulate perfectly.

It should always be remembered that a steady gentle warmth is far better than roasting the apparatus before a large fire; indeed, a great deal of damage

is done to electrical apparatus by foolishly exposing to a strong heat instruments which are partly put together with cement: the latter melts, and the symmetry and perfection of a piece of apparatus is often entirely spoilt; because it requires some experience to cement a brass cap on to a glass vessel, and the young electrician can do little or nothing with his apparatus when the cement is melted and running down the inside or outside of it.

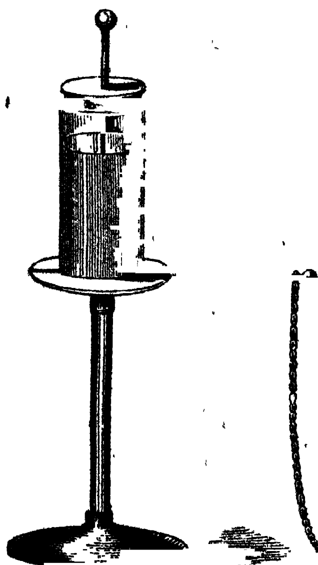


FIG. 227.—*Franklin's Experiment with the Insulated Jar.*

The interior of the jar is now connected with the ball of the prime conductor of the electrical machine, and, after receiving some sparks, it will be noticed that they cease to pass, and that the conductor is showing, by its electrical brushes and discharges through the air, that there is no charge passing into the Leyden jar.

When removed from the conductor, by pushing the insulating stand on one side, and tested with the discharger, little or no spark is perceptible. If, however, the wire and ball on which the Leyden jar stands—usually inserted into and made movable on the top of the insulating stand—is now connected by a chain with the ground, the jar is very quickly charged, when sparks are received from the prime conductor.

The *rationale* has already been explained at page 240, but may be repeated here.

When insulated, the positive electricity naturally resident on the outside of the glass opposes any accumulation of positive electricity in the interior; the chain of particles is not continuously charged in the order of plus and minus, but is interrupted by plus coming in the wrong place; the order, however, is restored when the outside of the jar is connected with the ground, as the

natural positive electricity finds a channel through which it can escape, and no longer opposes the accumulation of the positive charge inside the jar.

When a number of jars are insulated on glass stands and placed in regular order, the knob of the first being connected with the prime conductor, the knob of the second to the outside of the first, the knob of the third in con-

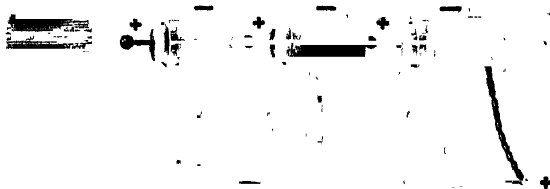


FIG. 228.—*Charging the Leyden Jar by Cascade.*

tact with the outside of the second, and the outside of this last connected with the ground, the whole series is charged by the first, because the first loses exactly the proportion of positive electricity which enters its interior; this passes to the second, which in its turn loses the equivalent from the outside, and finally passes or flows, as it were, into the third jar, the outside of which is connected with the ground. Thus the positive or plus electricity of the first jar, like a continuous cascade, flows from one jar to the other, and, all being charged, they cannot be discharged together; to effect this, the interior of all the jars must be connected together, and the same must be done with the exteriors.

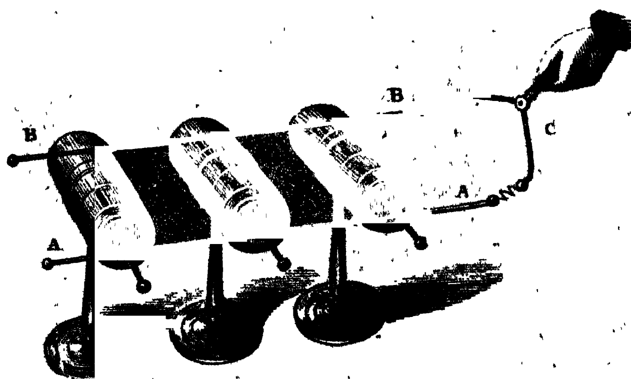


FIG. 229.—*The Jars turned round by their Insulating Glass Supports.*

A A, brass rod, laid on the wires and knobs connected with the interior of the jars, not by the hand, but with a silk thread; B B, brass rod, laid on *outside* of jars with hand; C, discharger, bringing the ends of two rods in conducting communication, and spark discharged.

Each jar can be turned round at right angles, and a brass rod, with balls at each end, suspended by a silk thread, can be laid across all the wires and knobs of the jars, and another wire laid along the exterior of the jars; then,

if the two extremities of the rods in conducting communication with the outsides and insides of the jars are brought in contact with the discharger, a brilliant spark and louder noise announces the discharge of the series of three jars which had been charged with electricity according to the original method discovered by Franklin.

Mr. Isham Baggs displayed some very brilliant experiments at the Polytechnic with Leyden jars, charged in the manner already described; and, by a particular mode of arranging them in positive and negative series, a very long and brilliant spark was obtained.*

It has been shown by the Franklin experiment that a jar cannot be charged unless the outside is placed in communication with the ground; it has also been pointed out that Leyden jars are usually charged by passing the electricity to the interior. A Leyden jar can, however, be charged from the exterior; and the arrangement for this purpose is shown at Fig. 230.

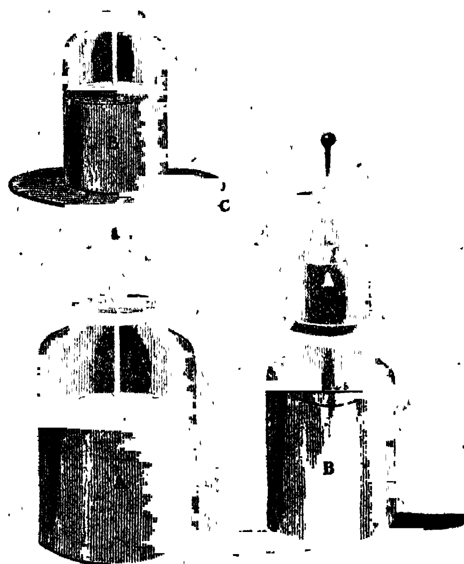


FIG. 230.—*The Leyden Jar charged from the exterior.*

A brass disc, C, is screwed on the top of the ball of the large jar A, in order to carry the smaller one B. When A is charged, B becomes polarized, but cannot accumulate a charge until the positive electricity from the inside is allowed to escape; this is done by touching the knob of B and the outside of A with the two balls of the ordinary discharger. A flash takes place when this is done, and now both A and B are charged. The inner surface of B is nega-

* "Journal of the Royal Society," Jan. 13, 1848

tive, the inside of A is positive; the outside of A is negative, the outside of B is positive.

Both jars may be discharged by using two dischargers: one connects the outside of A with the inside of B, thus bringing together the two negative surfaces; and the other discharger by touching the first one and then being advanced to the stage C, which represents the positive electricity, the usual flash and discharge follow directly the discharger comes within the striking distance.

A collection of Leyden jars, fitted up with wires and balls communicating with each other, and placed on a sheet of tinfoil, so that the exterior of the jars, like the interior, may be in conducting communication, constitutes what is termed a Leyden battery. (Fig. 223.)

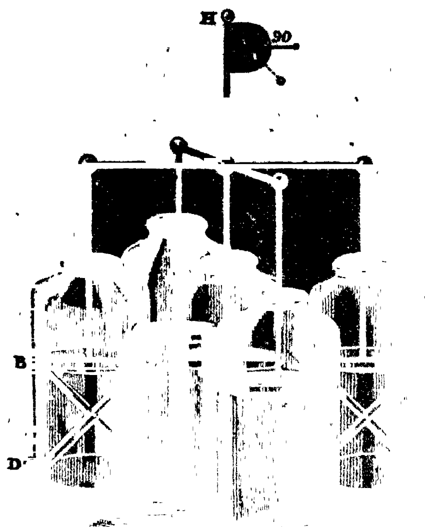


FIG. 231.—*The Leyden Battery.*

The five large jars are coated with tinfoil, and the brass balls belonging to each jar are supported by a method proposed by the Rev. F. Lockey, and recommended because it sometimes occurs that a jar will break during the discharge of the battery, although the electricity may pursue the path intended for it. Jars are more likely to break if the wire to which the ball is attached is carried down to the tinfoil inside. Direct metallic communication with one point of the interior of the jar is not so safe as having four contacts, and this is secured by the bar of wood, covered with tinfoil, and connected with two cross-pieces of thinner wood laths, also covered with tinfoil, and shown at A B, Fig. 231. It is evident that contact is made at two places, A, B, at the top, and two at the bottom, C, D.

The writer has in his possession two very large jars, which he coated with

tinfoil, after first pasting a coating of paper, such as paper-hangers use, on the jars, and allowing the paper to rise one inch above the tinfoil coatings. The jars expose a surface of six square feet of glass, and have been in use, without fracture, for the last twenty-five years, although frequently very highly charged, to break square pieces of mahogany, to demonstrate the mechanical power of the electric discharge. Young experimentalists would do well to avoid these trying experiments, as the electricity may prefer to break through the glass, instead of travelling only through the fibres of the wood.

Henley's electrometer, shown at H, Fig. 231, should always be inserted in one of the balls of the battery whilst it is being charged, as it indicates, by the rise of the arm carrying a light pith-ball, the amount of charge, and when it reaches 90° the jars are fully charged.

It is sometimes convenient to keep a jar charged for a considerable time, and particularly if the electricity is required for medical purposes; this is done by passing a glass tube through the wooden cover of the Leyden jar: the tube is lined half-way up from the bottom with tinfoil, and terminates at the top with a brass cap; to connect this with the interior of the jar, a wire with a loop at the top passes through the brass cap, and, after the jar is charged, may be removed by turning the jar upside down, when it tumbles out; or, better still, it may be taken away with a curved wire and ball, supported on a glass handle.

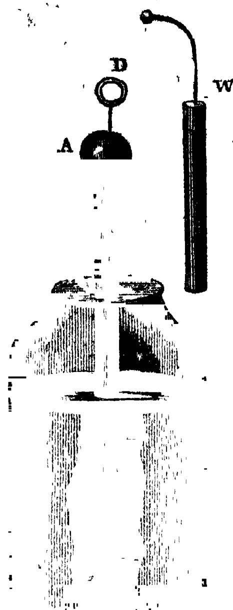


FIG. 232.—*The ordinary Leyden Jar, coated with Tinfoil,*

And containing the glass tube A A, capped with brass at A, and passing through the wooden top, which is usually cemented in and well varnished. C shows the height to which the tube is lined with tinfoil; D is the wire, with ring at the top, removable by the insulated curved wire W.

EXPERIMENTS WITH THE ELECTRICAL MACHINE, THE LEYDEN JAR, AND LEYDEN BATTERY.

I. The charging and discharging of a Leyden jar is beautifully shown by coating the inside and outside with diamond and spotted coatings, or little bits of tinfoil cut in the form of diamonds or spots, and pasted on so that an interval of glass surface may occur between each of them. When connected with the prime conductor, the jar presents a brilliant and most pleasing appearance during the time it is being charged, and also at the moment when the discharger is used; and the jar so coated is usually called a spangled jar.

II. Similar spots or small circles of tinfoil pasted round a glass tube show a brilliant spark between each interval or space left between the spots, when held to the prime conductor, or at the moment that the charge of a Leyden jar is sent through them. The tube is usually capped with brass at each end.

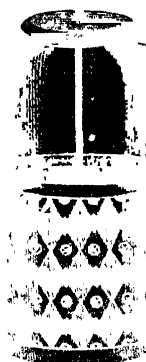


FIG. 233.
A Spangled Jar.



FIG. 234.
A Spangled Tube.



FIG. 235.

III. Narrow strips of tinfoil are arranged in parallel lines on a plate of glass, so that a continuous conducting strip, commencing with a ball at the top of the glass and ending with one at the bottom, is obtained.

The strips are then neatly cut out, so as to leave a small interval sufficiently wide to show the spark, and delineate in a succession of sparks any word, such as the name of

FARADAY.



FIG. 236.

IV. A glass bottle may be coated inside and outside with weak glue and rather large brass filings shaken inside and sifted over the glue outside. Of course, one side must be done first—viz., the inside; and the coating should be carried about as high as the usual coating of tinfoil. It should terminate top and bottom with a band of tinfoil, and it exhibits a very pretty effect when hung on to the conductor of the electrical machine, the outside being connected with a wire or chain with the ground. The intervals between the filings give rise to the most varied and beautiful appearances of lines and forked electric sparks; and as the jar discharges itself when the accumulation reaches a certain point, measured by the distance between the wire from the inside and the outside coatings, the effect is continuous as long as the electrical machine is turned.

V. A little tow wrapped round one of the balls of the discharger, and dipped in alcohol or ether, is set on fire directly the spark of the Leyden jar passes through it.

VI. A person standing on a stool with glass legs, and holding in one hand the chain from the prime conductor of an electrical machine in motion, may set on fire spirit or ether (held to him by some one else) in a metallic spoon, by merely allowing a spark to pass from his finger to the inside of the edge of the spoon. The hair of the person standing on the stool, and connected with the electrical machine, stands out in a very fantastic manner, if the hair is fine, silky, and well combed out previously.

VII. When a blunt wire, say ⅛ in. thick, and nicely rounded off at the end, is fixed into the conductor of an electrical machine (there are holes drilled expressly for putting in wires), as the handle is turned, a feeling like a gentle current of air is felt, when the face is approached to it, and, if the room be darkened, very pretty brush-like discharges are seen.

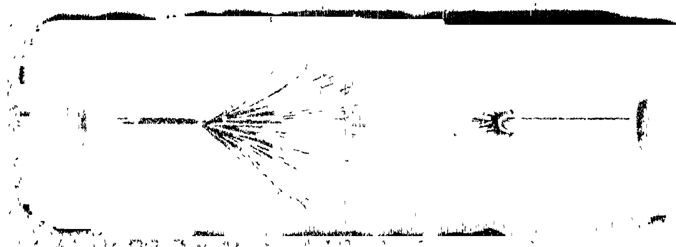


FIG. 237.

The brush discharge from a positively electrified wire. The reverse the concentration of the same brush into a glow or star when positive electricity is drawn towards the negative conductor. The one is the reverse of the other.

If the same blunt wire is placed in the negative conductor and the electrical machine put into rapid motion, a sort of glow or star is seen on the end of the blunt wire. In the first case, the positive electricity is escaping from the wire; in the second, it is going into and towards the wire.

VIII. An egg-shaped glass vessel, provided with a ground-glass plate, a collar

of leather at the top, and through which a brass rod and ball move so as to approach to or recede from another ball fixed into the lower cap, cemented on to the glass and provided with a stop-cock, is first,

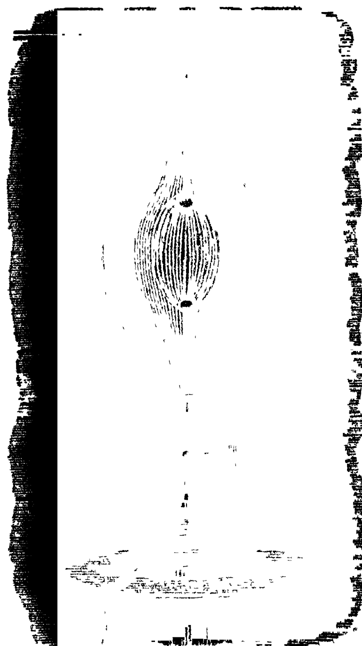


FIG. 238.

exhausted of air with the air-pump. Directly it is connected with the electrical machine, a beautiful glow [illegible] violet-coloured light is seen to pass between the balls.

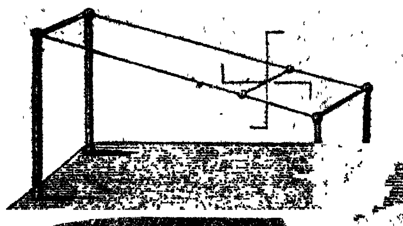


FIG. 239.

IX. The electrical inclined plane (Fig. 239) is formed by two inclined wires stretched between four glass pillars. When a very light rod of wood, covered with burnished gilt paper, having fine wires inserted at right

angles, with their ends all bent exactly alike, is placed on the wires which are connected with the conductor of the electrical machine, the rod revolves by reason of the reaction of the dispersed particles of electrified air upon those which are still, and it rolls up the inclined plane. If the experiment is tried in a darkened room, all the points exhibit pretty brushes of electric light.

X. If the inside of a clean dry tumbler or, better still, a German beaker glass, is held over the brass rod and ball of the conductor, and, after being well electrified, is put down over a number of light pith-balls



FIG. 240.—*The Electrical Dance of Puppets.*

placed on a metallic plate; the latter are attracted and repelled in the most amusing manner, and, if the glass will take a good charge, the effect lasts some time, and, when apparently stopped, may be often renewed by drawing the finger over various parts of the outer surface.

XI. Light pith figures, if well made and balanced, perform a sort of dance, by jumping up and down between a flat brass plate connected with the conductor and suspended opposite another plate connected with the ground (Fig. 240). When the shadow of the figure is cast on a disc, everybody can see the experiment, which then assumes gigantic proportions.

XII. A bell (Fig. 241) may be constantly struck with clappers, so arranged that, whilst the bell is insulated and electrified, the clapper is alternately attracted and repelled. Or, if the bell is placed in connection with the inside of a Leyden jar (Fig. 242), and the outside with another bell, the two being opposite to each other, and having between them a suspended clapper, the bells will continue to ring until the jar is discharged.

XIII. A very elegant experiment devised by Lichtenberg, and called after him Lichtenberg figures, is thus described by De la Rive:

"Lichtenberg figures make manifest without an electroscope, and in

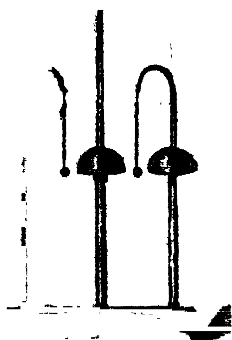


FIG. 241.—*The Electric Bell.*

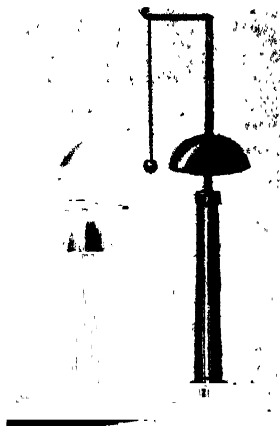


FIG. 242.—*The Leyden Jar and Bells.*

a directly visible form, the nature of the electricity with which the inner coating of a jar is charged. This experiment consists in slowly passing over a cake of resin (or flat plate of vulcanite) the knob of a Leyden jar, while the outer coating is held in the hand: we may even trace figures with the knob.

"The free electricity of the inner coating, which is constantly renewed in proportion as it escapes, because the other coating is held in the hand, remains adhering to all the points of the cake which the knob has touched.

"If, after having thus traced out lines with the knob of a jar charged interiorly with positive electricity, we trace others beside them with the knob of another jar charged with positive electricity, we may render each of them visible and distinct by powdering the cake with a powder formed of a mixture of sulphur and red lead *that have been rubbed together.* We perceive that all the particles of sulphur place themselves on the positive lines, and all those of red lead upon the negative; and they remain adhering there, even when we blow them or shake the cake strongly, so as to make the portion of the powder disappear which is not upon the parts of the surface that had been touched by the knob.

"The effect that we have just described arises from the particles of sulphur, during their mutual trituration, having acquired negative electricity, and those of red lead positive, which causes the former to pass upon the positive traces, and the latter upon the negative. We also remark that the sulphur forms a small tuft round each of the positively electrified points, whilst on each of the negative points the red lead leaves only a circular spot. This phenomenon, establishing, as it does, a very remarkable difference between the two electricities, is due to a more general cause.

"The property that we have thus recognised in resin, of retaining both

electricities adhering to its surface, is not peculiar to this substance alone: all bodies that are insulators possess it in a more or less marked degree. We have already seen that it exists in glass, when we electrized the interior of a glass jar, to produce the dance of pith balls. A Leyden jar, the coatings of which are movable (see Fig. 226), furnishes a further proof of this.

"The jar is charged as usual; then with an insulating handle the inner coating is lifted away, and afterwards the glass itself is lifted out: the two coatings, being thus detached, manifest no electrical signs. The two electricities have, in fact, remained adhering to the glass, the positive on the interior surface, and the negative on the exterior.

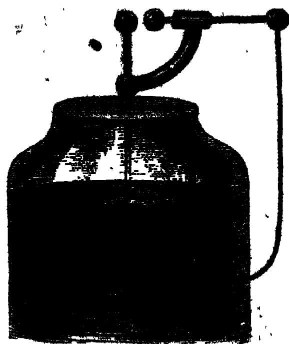


FIG. 243.—*Leyden Jar, with Lane's Discharger.*

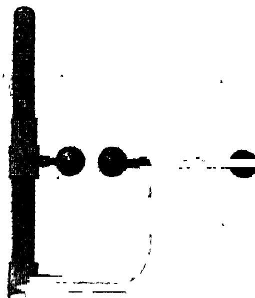


FIG. 244.—*Harris's Improved Lane's Electrometer.*

"These two electricities are recovered again by replacing the jar within its outer coating, and placing within it its inner coating; the discharge takes place between the two coatings as if they had not been deranged. The fact just pointed out explains why a Leyden jar always retains electricity after a first discharge, even when the latter has given rise to a strong spark. We can obtain a second discharge, much weaker, it is true, than the former, but yet very sensible, and sometimes, indeed, exceedingly violent, if the jar is large, and has been strongly charged.

"This second discharge arises from a portion of the two electricities having remained adhering to the glass after the first discharge, notwithstanding the contact of all the points of the two surfaces of the

jar with the metal surfaces; but the second discharge is generally sufficient to make all the remaining traces disappear."

XIV. A very portable and simple apparatus for obtaining electricity and charging a Leyden phial was arranged by Mr. Adams, an optician of the same date as Cavallo. It consists of a half-pint phial, coated inside with brass filings, and outside with tinfoil, and is charged by a varnished silk ribbon, which is rubbed by being passed through hare-skin rubbers placed, like finger-stalls, on the first and middle fingers of the left hand. The following directions are given for the proper manipulation of the silk rubbers:—Place the two finger-caps of hare-skin on the proper fingers; hold the phial at the same time at the edge of the coating, on the outside, between the thumb and first finger of the left hand; then take the ribbon in your right hand, and steadily and gently draw it between the two ribbons, over the two fingers, taking care at the same time that the brass ball of the jar is kept nearly close to the ribbon while it is passing through the fingers.

By repeating this operation thirteen or fourteen times, the electrical fire will pass into the jar, which will become charged, and, by placing the discharger against it, you will see a sensible spark pass from the ball of the jar to that of the discharger. If the apparatus is dry and in good order, you will hear the crackling of the sparks when the ribbon is passing through the fingers, and the phial will discharge at about the distance of half an inch from the balls.

XV. In order to regulate the proper discharge of single Leyden jars and batteries, very useful contrivances have been invented.

The arrangement (Fig. 243) consist of a bent glass arm, which is fixed to the rod and ball passing to the inside of the jar; the arm carries a tube through which a rod, with balls at both ends, slides. The distance between the two balls, one of which represents the interior and the other the exterior of the jar, is regulated according to the scale graduated on the sliding rod, so that a discharging spark of any required length (confined within the limits of the charged surface of the jar) may be obtained. Sir W. Snow Harris improved the arrangement of Lane's discharging electrometer, by making it an independent piece of apparatus, that might be adapted to one or more jars.

The exploding balls of this instrument (Fig. 244) are supported between a bent glass arm and a vertical tube of brass, and may be set at any given distance by means of a graduated slide. The bent arm of glass is attached, and is movable on a stout glass cylindrical rod, so as to insulate the whole, if required, and adjust the ball to be connected with the inside of the jar or battery to any given height. These and other pieces of electrical apparatus are made most correctly and elegantly by Messrs. Elliott Brothers, of 5 Charing Cross, the worthy successors of the old firm of Watkins and Hill, so long celebrated for their electrical apparatus.

XVI. Cuthbertson's Balance Electrometer is an extremely useful contrivance, where large Leyden batteries are required to be rapidly and uniformly discharged, as at the Polytechnic, where the deflagration of metallic wires is displayed. The apparatus consists of a wooden stand, in which two glass rods or supports are fixed; one of the insulating rods or pedestals supports a brass ball, which has a little hook

below it, for the convenience of attaching the chain passing from the outside of the Leyden battery; the other and higher glass pedestal supports a large brass ball, in which is arranged a long brass rod, supported on knife-edges, and acting like a balance; above this, and proceeding from the same large brass ball, is another rod and ball, placed so that the ball of the latter is exactly over, and almost touching, the other and lower one, that works on knife-edges.

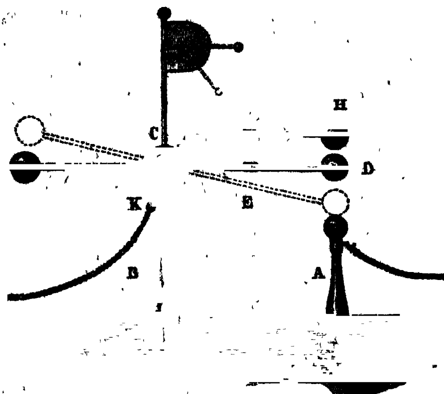


FIG. 245.—*Cuthbertson's Balance Electrometer.*

A, B, glass supports. The hook of A is connected by a chain with the outside of the battery. B carries the large ball through which the balance-rod, D, works. The sliding weight, E, like that of a steel rod, enables the experimenter to adjust the balance perfectly. H, the upper and fixed wire and ball, which, when sufficiently electrified by contact with the inside of the battery, by the hook and chain at K, repels the movable balance D, and, making the circuit complete (as shown by the dotted lines) by touching the brass ball on A, the whole discharge of the battery is sent through any substance.

With Cuthbertson's compound universal discharging electrometer, the experimenter may always have notice when the battery is nearly charged and ready, by inserting in the upper ball a Henley's quadrant electrometer, with graduated arc. The oscillation of the balance, when the battery is almost ready, will likewise serve to warn the person using it that he may expect the discharge to occur.

XVII. In connection with the Leyden battery, a Cuthbertson balance electrometer and Henley's universal discharger and press are always employed when a variety of substances are to be subjected to the powerful effects of a large charged surface of glass. The mechanical arrangements are such that the direction of the charge is certain and precise.

The annexed figure (246) hardly requires any explanation, as the parts are so simple. It consists of two glass legs, which support, by

hinged joints, two brass rods and balls with glass handles attached. The latter slides through tubes, and may be caused to advance or recede from each other, or they move right or left, as the hinged joints work in sockets.

The balls meet either on the little table, in which a piece of ivory is inserted, or the little table can be removed and the press substituted for it; as, for instance, when it is required to show the immense

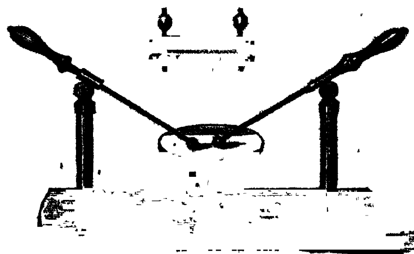


FIG. 246.—*Henley's Universal Discharger and Press.*

mechanical force of the electrical discharge by putting gold leaf between glass plates, and passing a charge through them, which shatters the glass to fragments, and frequently forces the gold leaf into the body of the glass. In this experiment, it is usual to put the glass plates in the press, and, to prevent accident from the pieces of glass flying about, it is better to cover the whole with a dry clean duster.

XVIII. Unscrew by a turn or two the balls attached to the arms of the Henley discharger; take some very fine iron wire, such as is used by silversmiths for making scratch-brushes, and having twisted a little in the crack or opening left by unscrewing the balls, screw them up again, when the thin wire will be held tightly, and, the length having been adjusted to the power of the Leyden battery employed, the whole is dispersed in minute white-hot globules when the electric charge is sent through the wire.

XIX. Place the balls of the Henley discharger on the little table, about one inch apart; put some gunpowder between them. When the discharge of the Leyden battery is sent across and through the gunpowder, it is not ignited, but every grain is dispersed and thrown away by the mechanical violence of the discharge, which occurs so rapidly, that the heat of the electric discharge does not appear to have time to affect the gunpowder.

When the great steam hydro-electric machine was in use at the Polytechnic, it was possible, by directing from a point the whole discharge of the mammoth machine for some minutes into a heap of gunpowder, to accumulate heat and set it on fire; but it was always very troublesome to do, and a great deal of steam had to be used to effect this object. If, however, a damp string formed part of the conducting arrangement, then the powder fired almost instantaneously, as

the damp string exercises a retarding action on the velocity of the current of electricity, and it then appears to have time to give its heat to the powder.

To fire gunpowder by the Leyden jar, a little cardboard tray may be placed on the table of the Henley discharger; and in order not to spoil the polish of the balls, two copper wires are thrust through the sides of the tray containing the powder, and the brass balls of the Henley discharger connected with them. A wet string may be tied to one rod and also to an ordinary discharger, the other rod being connected by a chain with the exterior of the Leyden jar; the ordinary discharger with the wet string is made to touch the knob, and, although it sometimes fails, the powder is very generally ignited directly contact is made. To fire gunpowder, a wet string must form part of the circuit. The powder may be placed in a closed case or cartridge, so that it cannot be scattered by the mechanical violence of the discharge.

Sturgeon retards the velocity of the discharge by placing the gunpowder in a boxwood cup which is insulated and connected with the outside of the jar. An insulated brass wire and ball is placed directly over the cup, and, directly contact is made with this and the interior of the Leyden jar by the ordinary discharger, the powder is usually fired.

XX. A piece of mahogany, about two inches long and $\frac{3}{4}$ in. square, may be split by passing the discharge into and through it by two copper wires inserted about half an inch, one at each end. The softer the wood, the safer the experiment so far as the jars are concerned, and, as already observed at page 255, this experiment must not be pushed too far by using larger and thicker pieces of wood.

XXI When a lighted composite candle is blown out carefully, there rises from it a column of gas and smoke, which is inflammable. If such a candle is placed on the table of the Henley discharger, and the balls adjusted so that the spark will go through a point just above the burning wick, and the whole connected with a charged Leyden jar, the spark will relight the candle, if, simultaneously with the blowing out of the flame, contact is dexterously made with the Leyden jar.

FIG. 247.—*The Electric Bomb.*

XXII. The expansion which air undergoes during the passage of an electric discharge through it is shown by a very nicely constructed mortar, to the mouth of which is accurately fitted a ball of some light wood.

When the discharge passes, the ball is forced out; and if the whole is made of ivory (Fig. 246), the effect is very certain. The expansion of the air in this experiment will help the student to understand why so much noise (thunder) is heard when the electrical discharge takes place from hundreds of acres of charged clouds.

XXIII. The experiment called the "Shooting Star" is extremely beautiful, but, like many other illustrations, requires considerable pains to be taken in order to obtain a good result. In the first place, a long tube must be provided at least four feet in length; this is properly capped, and provided with a stopcock at one end and a plain cap on the other, which should be nicely rounded off, and inside the cap a small ball may be screwed. The electrical machine being in good order, and the Leyden battery, of six square feet of glass, warm and dry, one assistant may proceed to charge it gradually, whilst another may be pumping the air out of the long tube. When the electrometer shows that the battery is nearly charged, one end of a chain is attached to one of the balls of the discharger, and the other end to the top of the long tube. The air-pump or stopcock end of the tube is, of course, in conducting communication with the outside of the battery jars. The circuit is now suddenly completed, and sometimes a continuous flash through the whole length of the tube marks the discharge of the battery; but it may occur that it discharges itself in a brush, and that the battery must be recharged, and the experiment tried again. To insure perfect success, the experiment should be tried with a barometer attached to a pump, and then it will soon be ascertained what vacuum is the best for the experiment. Success greatly depends on the right management of the vacuum, which must not be a perfect one.

XXIV. The velocity of electricity, and the consequent amazing rapidity of the spark-discharge, and appearance or disappearance of the light, is admirably shown by Mr. Rose's photodrome apparatus described at p. 85, Fig. 95.

The writer uses the disc four feet in diameter, having a series of black balls painted on a white ground; when this is rotating three hundred times in a minute, and the black balls have all merged one into the other, according to the law of persistence of vision, already explained at p. 84, they produce (instead of twelve distinct black balls) three continuous rings, dark in the centre, and lighter towards the edges, because there the greatest surface of the white disc is exposed. The disc should be illuminated with a lime light and lens, and, directly this is cut off, a Leyden jar, provided with a Lane's discharger, is permitted to discharge itself regularly, by keeping the electrical machine in motion; all the black balls now return, and the disc, though going round three hundred times in a minute, appears frequently to stand still.

The same fact is observed during a storm at night, accompanied with thunder and lightning; all objects seen by the light from the electric flash appear to stand still, although they may be in rapid motion at the time. Captains of ships have frequent opportunities of noticing this: a storm comes on suddenly, and some, if not all, the sails of the ship require to be furled; the command is given, up fly the sailors, and the deck and rigging swarm with men who are actively engaged;

but if at this moment the ship is illuminated with a flash of lightning, every officer, every man, the ship tossing about, and the waves of the sea, all appear at rest; as if they were parts of a magnificent stereoscopic picture.

The fact is, that the light from a flash of lightning, as proved by Sir Charles Wheatstone, comes and goes in the millionth part of a second; so that before the wheel, going round three hundred times in a minute, has time to move, the electric light has arrived and passed away. The same thing occurs with all other movements viewed with the electric flash, and the fleetest racehorse even, under these circumstances, would actually appear to be standing still.

XXV. Many years ago, Sir Charles Wheatstone invented a most ingenious arrangement for measuring the velocity of electricity through a copper wire, and it was from these experiments he deduced the almost instantaneity of the light from the electric spark.

His apparatus consisted of a Leyden jar, which was charged in every experiment to the same amount, and the discharge sent through a copper wire about half a mile long.

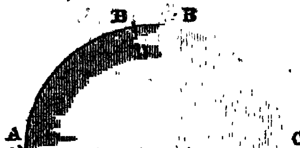


Fig. 248.

The copper wire was insulated and interrupted at three points, viz one, A A, within a few inches of the inner coating, one at the middle of the circuit, B B, and one at the same number of inches of the outer coating, C C, of the Leyden jar as the first which was in contact with the inner coating. A very cleverly arranged insulated dis (Fig. 248) contained the three breaks in the circuit, where the spar discharges took place; so that when the Leyden jar was discharged all the sparks could be seen at once, and were reflected in a sma

revolving mirror. If observed without the mirror, the three sparks appeared to occur simultaneously; but when looked at in a small revolving steel mirror through a plate of glass, the sparks, according to the law of persistence of vision, become lines of light, of which two are equal, whilst the third, representing the middle of the circuit, is sufficiently delayed to give a shorter line, and, as the velocity of the steel mirror is known, by a proper register, the exact angular deviation of the image of the central spark is easily obtained; and from these data the retardation of the current by the long copper wire is correctly calculated.



FIG. 249.—*Apparatus, made by Messrs. Elliott, to show the time occupied by the transmission of an Electric Current by reflection.*

B, the revolving mirror.

The three sparks, when seen in the revolving mirror, appear as three straight bright lines; and, if the motion is very fast, the lines assume the appearance A, Fig. 250, when the mirror is rotated to the

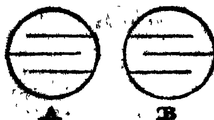


FIG. 250.—*Lines of Light reflected from Revolving Mirror.*

right; but, if reversed, then they appear as in B, Fig. 250; but the lines were never seen as at C or D, Fig. 250, which should have been the case according to the Franklinian theory of a single fluid. Thus

Wheatstone's ingenious and beautiful experiment supports most powerfully the theory of the two fluids, which seem to meet in the centre of the wire, as if they rushed with equal speed to unite with and neutralize each other.

The spark disc (Fig. 249) was placed 10 ft. away from the revolving mirror, and the summing-up of the experiments gave the following conclusions:

1. That electricity travels, through a copper wire arranged as in the experiment described, faster than light in its passage from the sun.

2. That the electricities of the two kinds, viz., that from the interior of the jar and the other from the exterior, travel at the same velocity, and meet in the middle of the wire.

3. That the light from the electric flash or spark-discharger does not last longer than the millionth part of a second.

4. That the delicate optic nerve is capable of appreciating an interval of that duration, or, in other words, can see objects which are only illuminated for the millionth part of a second.



FIG. 251.—*Appearance of the Card after sending the discharge through Silver Wire 1-300th of an inch thick.*

XXVI. Very fine gold, silver, copper, brass, and iron wires can be obtained of Messrs. Johnson and Matthey, at their assay office in Hatton Garden. About three inches of either metallic wire is stretched across a plain white card by making a small cut in the card at the opposite ends, and then placing the wire in the cuts, which may be neatly closed with little slips of tinfoil.

The card with the wire is then covered with another card, and placed between the boards of the little press attached to Henley's universal discharger (Fig. 245, p. 264). When tightly screwed up and the brass balls of the discharger brought in contact with the ends where the tinfoil marks the termination of the two ends of the wire, the discharge from the Leyden battery can then be sent through it. The result is that the wire is completely disintegrated,

and so perfectly divided that nothing remains upon the two cards but certain curious marks (Fig. 251), which are no doubt caused by the finely divided metal being driven bodily into the card,—although it is usually ascribed to oxidation, and this may be the case with metals which unite easily with that element. When a very thin iron wire is deflagrated alone by passing the battery discharge through a length of nine or twelve inches, the effect is very beautiful, as it is dispersed in a shower of red-hot globules, which are well displayed in a darkened room.

The dissipation of gold by a powerful electrical discharge can also be shown in a similar manner. The metal is vaporized, and disappears in the form of a red vapour.

By receiving the vapour from gold on a piece of silk, a portrait or other figure may be printed upon it. To obtain these portraits a likeness of any known personage is cut out in a small piece of cardboard, so that, if held against the wall with a candle behind it, the shadow cast indicates that the portraiture is successful; the portrait-card is now laid upon a sheet of gold leaf pasted to another card; and, as the electrical discharge would act unequally upon the gold if merely conveyed through the brass balls of the discharger, it is usual to paste a slip of tinfoil on the opposite edge of the gold leaf, thus bringing all the gold at once in conducting communicating with the brass balls.

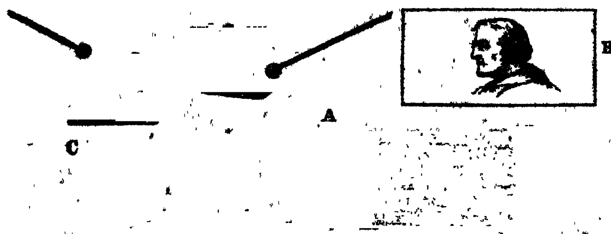


FIG. 252.

A, card covered with gold leaf, and edges prepared with tinfoil; B, portrait-card; C, the two cards, A and B, in press, and in contact with the brass balls of the discharger.

XXVII. With the powerful hydro-electric machine at the Polytechnic (p. 273) (to be hereafter described) a most beautiful effect was produced by sending the discharge through a long chain composed of beads of glass and copper strung on a stout silk cord; and as the latter was at least forty feet in length, the effect was very imposing.

On the smaller scale a piece of brass chain, hung in festoons on a plate of glass blackened at the back, affords a very pretty experiment, being illuminated throughout its entire length when the electrical discharge is sent through it.

XXVIII. To imitate and demonstrate the effects of discharges of natural electricity, or lightning, on buildings, &c., many ingenious models, such as the gable end of a house, a pyramid, a powder-magazine,

a ship, or mast of a ship, are made by Messrs. Elliott, of the Strand, London.

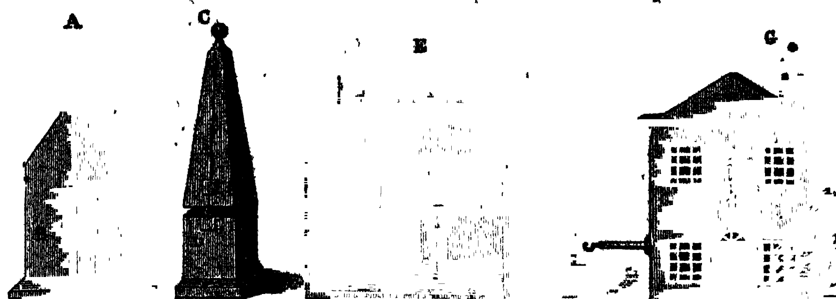


FIG. 253.

All these models act upon one principle, viz., that as long as the conductor is continuous throughout and unbroken, no harm or damage occurs to the model; but directly the conducting chain is broken, by removing or altering the position of some part of the conductor, then the following results occur. In the first place, the charged cloud is represented by Sir William Snow Harris's thunder-cloud needle (Fig 254), formed by a brass horizontal rod or needle balanced and movable upon the point of a vertical metallic rod connected with the interior coating of a large Leyden jar.



FIG. 254.—*Harris's Thunder-cloud Needle.*

One end is covered with the finest cotton wool: a little good gun-cotton increases the effect, as it may be so arranged that every time the flash occurs the cotton shall ignite, and the sudden flash with the crack and light of the spark is remarkably telling. The cotton is intended to represent a cloud hovering over the chimney or highest part of a house or church-steeple; and, when the jar has been sufficiently charged, it is attracted, according to the law of induction, to the nearest object, and the simulated cloud descends upon the top of the model, at the same time discharging the jar

through the parts of the models. As before stated, when the lower portion of the conductor attached to either of the models is connected with the outside of the jar by a chain, the Harris's thunder-cloud needle being in connection with the interior of the jar, the discharge causes no change in the disposition of the parts of the toy model; but if, as in A, Fig. 253, the little piece of square wood at B is turned round at right angles, the continuity of the wire is broken, and it is blown out when the discharge takes place. The model B maintains its erect position if the conductor is undisturbed; but when a little bit of tinfoil is removed from D, it topples over in the most natural fashion when the miniature thunder-cloud is discharged upon it.

The model E affords a good bang, and the roof is blown off when the powder in the tube F is ignited; but care must be taken not to use too much gunpowder. The writer well remembers helping poor young Mr. John Cooper, many, many years ago, at a lecture delivered at the Southwark Institute, and, being directed *sotto voce* to give them a "good one," he attended too implicitly to his instructions. Luckily, this was the concluding experiment: the powder-house blew up with astounding effect; but, unfortunately, the roof descended into the middle of a large cylindrical electrical machine, and the result, of course, was total annihilation. The audience, it is believed, thought it was all part of the experiment, and applauded in the most *cheering* manner; but the glances exchanged between the lecturer and his assistant were of the most desponding kind, considering that the large electrical machine had only been borrowed for the occasion.

G, Fig. 253, is called the "fire-house," and exhibits the heat of the electrical discharge, and its power to set fire to gun-cotton or tow dipped in ether or alcohol; and, as it is made of tin and glazed with glass windows, the conflagration inside betrays the lamentable effects that might and do occur when houses are struck and set on fire by lightning.

XXIX. A lightning conductor, if intended to last, should be made of copper rod, at least half an inch—better three-quarters—in diameter. It should be carried above the highest chimney-top, and be well pointed and doubly gilt; the lower end must be carried down to the clay, and must enter the first stratum of earth known to be always damp. If the building is a long one, it is better to have a lightning conductor at each end, as a cloud, in coming up to a lightning conductor, is always discharged through the shortest road; and if a chimney-pot at the other end of the building rises as high as the lightning conductor at the other end, it may divide the honours and dangers of the discharge with the conductor, provided the cloud arrives at the side opposite to that where the metallic safety-rod is fixed.

XXX. The hydro-electric machine affords a magnificent example of electricity derived from friction, and it continued for a lengthened period to be one of the greatest attractions at the Polytechnic. In the "Philosophical Magazine," vol. vii., appeared a letter from Mr. (now Sir William) Armstrong, giving a curious and most inte-

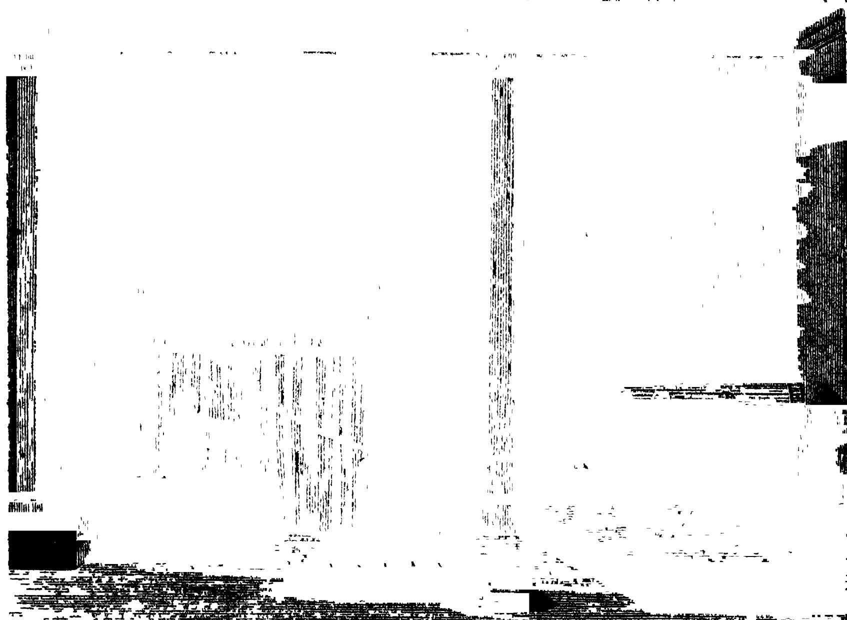


FIG. 255.—*The Hydro-Electric Machine at the Polytechnic.*

resting description of the accidental production of the electric spark by high-pressure steam escaping through a fissure or crack in the cement by which the safety-valve ought to have been fitted in steam-tight to the boiler of a locomotive standing at Sedgehill, six miles from Newcastle. Every time the engine-man passed his hand through the steam he received an intense electric spark, which he spoke of as "fire." Mr. Armstrong investigated the phenomena, and, continuing a very laborious and clever series of experiments, arrived by gradual steps to the production of a perfect steam machine, in which the particles of water, impelled by steam, rubbing against the interior of a series of jets lined with partridge-wood, produced effects which have never been surpassed in England. At that time Dr. Bachoffner was the very popular lecturer on Natural Philosophy at the Polytechnic, and he assisted at and conducted most patiently the vast number of experiments which had to be carried out before the ponderous machine was considered ready to be exhibited to the public. With Dr. Bachoffner were of course associated the contriver, Mr. Armstrong, and Mr. Walker; and fearful that our readers may think the writer too prone to talk of Polytechnic doings, he has preferred to take Dr. Noad's account of the machine as exhibited fifteen years ago at that Institution:

"Shortly after these experiments were made, the directors of the Polytechnic Institution determined on constructing a machine, on a large scale, for the purpose of producing electricity by the escape of steam; and under the superintendance of Mr. Armstrong, assisted by Dr. Bachoffner, the 'Hydro-Electric Machine' was finished, and placed in the theatre of the Institution, where by its extraordinary power it soon excited the astonishment of all who beheld it. The machine consists of a cylindrical-shaped boiler, similar in form to a steam-engine boiler, constructed of iron plate ⅜ in. thick; its extreme length is 7 ft. 6 in., one foot of which being occupied by the smoke-chamber makes the actual length of the boiler only 6 ft. 6 in.; its diameter is 3 ft. 6 in. The furnace and ash-hole are both within the boiler. When it is required entirely to exclude the light, a metal screen is readily placed over these. By the side of the door is the water-gauge and feed-valve. On the top of the boiler, and running nearly its entire length, are forty-six bent iron tubes, terminating in jets having peculiar-shaped apertures, and formed of partridge-wood, which experience has shown Mr. Armstrong to be the best for the purpose; from these the steam issues. The tubes spring from one common pipe, which is divided in the middle, and communicates with the boiler by two elbows. By this contrivance the steam is admitted either to the whole or part of the tubes, the steam being shut off or admitted by raising or lowering the two lever handles placed in the front of the boiler. Between the two elbows is placed the safety-valve for regulating the pressure, and outside them, on one side, is a cap covering a jet employed for illustrating a certain mechanical action of a jet of steam, and on the other a loaded valve for liberating the steam when approaching its maximum degree of pressure. At the further extremity of the boiler is the funnel-pipe or chimney, so contrived that, by the aid of pulleys and a balance-weight, the upper part can be raised, and made to slide into itself (similar to a telescope), so as to leave the boiler entirely insulated. To prevent as much as possible the radiation of heat, the boiler is cased in wood, and the whole is supported on six stout glass legs, 3½ in. diameter and 3 ft. long. In front of the jets, and covering the flue for conveying away the steam, is placed a long zinc box, in which are fixed four rows of metallic points, for the purpose of collecting the electricity from the ejected vapour, and thus preventing its returning to restore the equilibrium of the boiler. The box is so contrived, that it can be drawn out or in, so as to bring the points nearer or further from the jets of steam: the mouth or opening can also be rendered wider or narrower. By these contrivances the power and intensity of the spark is greatly modified. A ball-and-socket joint, furnished with a long conducting-rod, has been added to the machine, so that by its aid the electricity can be readily conveyed to the different pieces of apparatus used to exhibit various phenomena. The pressure at which the machine is usually worked is 60 lbs. on the square inch.

"As it is now fully established that the electricity of the hydro-electric machine is occasioned by the friction of the particles of water, the latter may be regarded as the glass plate of the common electrical machine, the partridge-wood as the rubber, and the steam as the rubbing power. The electricity produced by this engine is not so remarkable for its high intensity as for its enormous quantity. The maximum spark obtained by Mr. Armstrong in the open air was 22 in., the extreme length under present circumstances has been 12 or 14 in.; but the large battery belonging to the Polytechnic Institution, exposing nearly 80 ft. of coated glass, which under favourable circumstances

was charged by the large plate machine, 7 ft. in diameter, in about 50 seconds, is commonly charged by the hydro-electric engine in 6 or 8 seconds. The sparks which pass between the boiler and a conductor are exceedingly dense in appearance, and, especially when short, more resemble the discharge from a coated surface than from a prime conductor. They not only ignite gunpowder, but even inflame paper and wood shavings when placed in their course between two points. In the 151st number of the 'Philosophical Magazine,' a series of electrolytic experiments made with this machine are described by Mr. Armstrong. True polar decomposition of water was effected in the clearest and most decisive manner, not only in one tube, but in ten different vessels, arranged in series, and filled respectively with distilled water, acidified with sulphuric acid, solution of sulphate of soda tinged blue, and red solution of sulphate of magnesia, &c., &c., and the gases were obtained in sufficient quantities for examination.

"The following curious experiments are likewise described:

"Two glass vessels containing water were connected together by means of wet cotton. On causing the electric current to pass through the glasses, the water rose above its original level in the vessel containing the negative pole, and subsided below it in that which contained the positive pole, indicating the transmission of water in the direction of a current flowing from the positive to the negative wire. Two wine-glasses were then filled nearly to the edge with distilled water, and placed about 4-10ths of an inch from each other, being connected together by a wet silk thread of sufficient length to allow a portion of it to be coiled up in each glass. The negative wire, or that which communicated with the boiler, was inserted in one glass, and the positive wire, or that which communicated with the ground, was placed in the other. The machine being then set in action, the following singular effects presented themselves:

"1. A slender column of water, inclosing the silk thread in its centre, was instantly formed between the two glasses, and the silk thread began to move from the negative towards the positive pole, and was quickly all drawn over and deposited in the positive glass.

"2. The column of water, after this, continued for a few seconds suspended between the glasses as before, but without the support of the thread; and when it broke, the electricity passed in sparks.

"3. When one end of the silk thread was made fast in the negative glass, the water diminished in the positive glass, and increased in the negative glass, showing, apparently, that the motion of the thread, when free to move, was in the reverse direction of the current of water.

"4. By scattering some particles of dust upon the surface of the water, it was soon perceived by their motions that there were two opposite currents passing between the glasses, which, judging from the action upon the silk thread in the centre of the column, as well as from other less striking indications, were concluded to be concentric, the inner one flowing from negative to positive, and the outer one from positive to negative. Sometimes that which was assumed to be the outer current was not carried over into the negative glass, but trickled down outside of the positive one, and then the water, instead of accumulating, as before, in the negative glass, diminished both in it and in the positive glass.

"5. After many unsuccessful attempts, Mr. Armstrong succeeded in causing the water to pass between the glasses without the intervention of a thread for

several minutes, at the end of which time he could not perceive that any material variation had taken place in the quantity of water contained in either glass. It appeared that the two currents were nearly, if not exactly, equal, while the inner one was not retarded by the friction of the thread. Mr. Armstrong likewise succeeded in coating a silver coin with copper, in deflecting the needle of a galvanometer between 20° and 30°, and in making an electro-magnet by means of the electricity from this novel machine.

"Extraordinary as is the power of the Polytechnic machine, it was afterwards entirely eclipsed by a similar apparatus constructed at Newcastle under the direction of Mr. Armstrong, and sent out to the United States of America. In the arrangement of this machine, the boiler of which is not larger than that at the Polytechnic Institution, Mr. Armstrong introduced certain improvements, suggested by the working of the latter, and which had reference to those parts of the apparatus more immediately concerned in the production of the electricity, viz., the escape apertures and the condensing pipes. It was found to be a matter of extreme nicety to adjust the quantity of water deposited in the condensing pipes, so as to obtain the maximum excitation of electricity. If, on the one hand, there be an excess of water, then two results will ensue, each tending to lessen the electricity produced:—1st, the mean density of the issuing current of steam and water is increased, which causes the velocity of efflux, and consequent energy of the friction, to be diminished; and, 2ndly, the ejected steam-cloud is rendered so good a conductor by the excess of moisture, that a large proportion of the electricity manifested in the cloud retrocedes to the boiler, and neutralizes a corresponding proportion of the opposite element. On the other hand, if the quantity of water be too small, then, although each particle of water may be excited to the fullest extent, the effect is rendered deficient, in consequence of the insufficient number of aqueous particles which undergo excitation.

"In the Polytechnic, arrangement for condensation of the steam in the tubes is effected by contact with the external air; and when the density of the steam in the boiler is diminished rapidly, they do not cool down with sufficient rapidity to condense the requisite quantity of water. To remedy this defect in the American machine, Mr. Armstrong adopted a method of condensing by the application of cold water. A number of cotton threads were suspended from each condensing pipe into a trough of water, from which, by capillary attraction, just as much water was lifted as was required for the cooling of the pipe, since it was easy, by increasing or diminishing the quantity of cotton, to increase or diminish the supply of cold water; and this method of keeping down the temperature proved so effective, that two or three times the number of jets that were before used could now be employed. The number in the American machine was 140, ranged in two horizontal rows, one above the other, on the same side of the machine. The sparks obtained, though not longer than those upon the London machine when it stood in the open air, succeeded each other with three or four times the rapidity, and, even under unfavourable circumstances, charged a Leyden battery, consisting of thirty-six jars, containing 33 ft. of coated surface, to the utmost degree that the battery could bear, upwards of sixty times in a minute, being equivalent to charging nearly 2000 ft. of coated surface per minute, which is at least twenty times greater than the utmost effect that could be obtained from the largest glass electrical machine ever constructed."

The Polytechnic apparatus, itself unique, enormous, and powerful, was well

adapted for the purposes of the Institution, but could not be carried about or fitted up in another lecture-room. The writer had a portable apparatus fitted up, which gave safely, on the small scale, all that could be witnessed with the great hydro-electric steam machine. It consisted of a cylindrical furnace and strong copper boiler, supported on a stool with stout glass legs, each of which rested on a disc of shellac. The boiler was provided with a safety-valve and all necessary taps, and proceeding from it, and fitted with a ball-and-socket joint, was a copper tube, 1 in. in diameter, curved round, and having a hollow copper ball at the end, to which three stop-cocks were fitted. Whilst steam was getting up, the copper tube was left off the boiler, and only screwed on just before the experiments were shown.

The chimney of the furnace was so arranged that the portion connected directly with the furnace could be removed, disclosing a square iron box, into which a few pieces of burning charcoal were placed, so that, when the copper tube and ball were screwed on, the first stop-cock exactly faced the iron box containing the charcoal; and, of course, when the steam was turned on, it blew out of the latter into the charcoal, and, causing the charcoal to burn with greater rapidity, created a good draught, which carried off the steam, and prevented it doing harm to the other electrical apparatus, which had to be kept dry and warm.

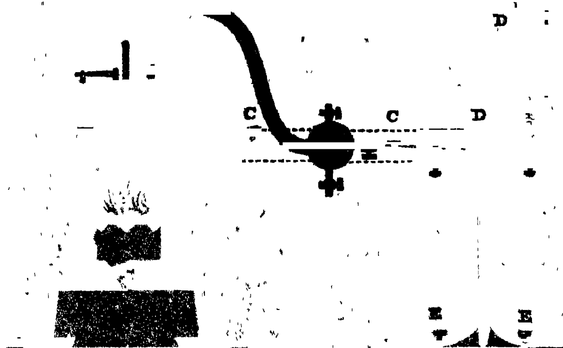


FIG. 256.—*Portable Apparatus for showing the Electricity of Watery Steam.*

A is the copper boiler, safety-valve, copper curved tube, with hollow ball and three stop-cocks; the lower one enables the operator to remove condensed water, the upper one to introduce any different fluid; the third contains the jet made of hard partridge-wood (Fig. 257), from which the watery steam escapes into the charcoal-box and chimney, D D. The dotted lines, C C, show the portion of the chimney removable before the experiments commence, in order to insulate the furnace B, which stands on a stool with strong glass legs, resting on plates of shellac.

The operator must remember to keep a sufficient quantity of damp sand in the bottom of the ash-pit, which should be regularly wetted by the assistant, or the stool may catch fire, and great confusion caused by this untoward result. The chimney D D is rendered independent of all extraneous support by being attached to a strong iron pillar with claw feet, screwed to the floor with (E E)

Stage-screws, *i.e.*, spiral screws with handles, much used for theatrical purposes, to support small bits of scenery on a stage.

The boiler being insulated, and the steam up to a pressure of at least 30 lbs. on the square inch, a number of interesting experiments may be performed.

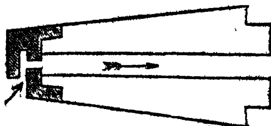


FIG. 257.—*Section of the Jet used for the Hydro-Electric Machine*,

Being a conical plug of hard wood (partridge-wood is preferred), terminated by a brass mouth-piece. The shaded parts are brass.

I. Mere emission of *dry* steam produces no electricity, and will hardly affect the gold leaves of an electroscope.

II. The copper ball is now purposely cooled a little by pouring cold water and applying a wet flannel to it, so as to obtain some condensed water; and now, when the steam is turned on, the usual signs of electrical excitement become apparent, and sparks are easily procurable. The handles of the stop-cock must be covered with flannel, or the operator will be unable to manipulate the opening and shutting of them. The *watery* steam, rushing through the tube, evolves electricity, because the particles of water forced through by the jet of steam rub against the inside of the jet, thus proving in a satisfactory manner that friction is the exciting cause, and not the mere change of form of water into steam. The copper boiler, whilst the steam is issuing, is negatively electrified; the issuing steam, positively.

III. The steam being raised to 50 lbs. on the square inch, the electric spark, the inflammation of combustible matter, and the charging of the Leyden jar, can be displayed, the boiler and steam remaining in the same state of electricity.

IV. Altering the rubbing fluid, by substituting oil for the water in the copper globe (easily done by pouring in a few drops of oil of turpentine through the upper stop-cock), changes the state of the electricity of the boiler from negative to positive, and the steam from positive to negative, because the globules of water become coated with oil, and thus expose a different surface against the rubber, viz., the inside of the hard partridge-wood jet.

V. The electrical exaltation is destroyed for a time by putting a solution of common salt into the copper globe, because the particles of water are then made good conductors, and as fast as the electricity is obtained it is neutralized (returned again to the boiler), just like rubbing a piece of sealing-wax with a damp flannel. The gradual rise and return of the electrical force is shown, as the conducting matter, the salt, is blown out of the copper globe, as if the damp flannel had been dried, and thus lost its conducting power.

VI. Dry steam or dry air will not excite electricity whilst rushing through a tube; this is easily proved by getting the copper tube and globe as hot as possible, and then allowing the steam to issue from the jet.

So also with air: the mere fact of allowing air to rub against the inside of the nozzle of a common pair of bellows will not eliminate the electric force; but if a little whitening or powdered chalk is introduced, as a substitute for the watery particles in the steam experiment, the electricity is produced, and is shown distinctly if the whitening is blown out on to the cap of the electroscope.

VII. By connecting an insulated platinum capsule, containing water, by a wire, with an electroscope, and evaporating the water, no electricity can be rendered evident; if, however, a piece of red-hot charcoal is placed in the platinum capsule, and a little water suddenly poured upon it, and provided the ebullition is sufficiently violent to cause the particles of water to rub against the sides of the capsule, then electricity is sometimes eliminated.

From these experiments it may be concluded that evaporation unattended by friction, as from the surface of the oceans, rivers, lakes, is not a source from whence electricity in nature is obtained, and we must therefore look to some other cause for the explanation of the production of atmospherical electricity.

SUMMARY OF THE LAWS OF ELECTRICAL ACCUMULATION.

The young students who wish to travel easily through the chapters on voltaic electricity, magnetism, and electro-magnetism will do well to make themselves well acquainted with the laws which relate to frictional electricity, as they will find them reproduced in more complicated forms as they proceed with the consideration of the most important branches of science, with which all well-educated persons should be acquainted.

I. Experiments would show, and especially those which relate to the velocity of the passage of an electrical discharge through a copper wire half a mile in length, performed by Sir Charles Wheatstone, p. 267, that the idea of the existence of two forces, the one called "vitreous" and the other "resinous" electricity, seems to be more rational and better capable of proof than the Franklinian theory that supposes the existence of one fluid only; and this idea is further supported by Armstrong's curious experiments with the Polytechnic hydro-electric machine, paragraphs 1 to 5, page 275.

II. Similar electricities repel, dissimilar attract, each other.

III. There is no absolute difference between insulators and conductors,—it is shown that they may both assume polarity; but, in the former case, the polarity lasts only so long as the disturbing cause exists; in the latter, as with glass and resin, the polarity set up is maintained. These are called dielectrics, because they are capable of polarization.

IV. Electrical induction means that disturbance of electrical equilibrium which occurs when an electrified body is brought towards another which is in a quiescent state.

V. Faraday's theory of induction has overturned all previous hypotheses. "Electrical induction is an action of contiguous particles." Every of air between a piece of excited glass and the cap of an is supposed to be in a polar state. . .

As long as the particles maintain their polarization, *insulation* is secured; but when the particles discharge themselves one into the other, then a neutralization occurs, and the non-maintenance of polarization is called *conduction*.

Even a Faraday could occasionally write vaguely. It is sometimes better to take the epitome of a philosopher's assumptions through another mind, and this want is admirably supplied by the late Professor Daniell, of King's College, London:

"Up to the date of his discovery, the phenomena of induced electricity were supposed to arise from an action of a charged body upon others at a distance, in straight lines, through non-conducting media, the particles of which were assumed to be unaffected by it; he has shown induction, on the contrary, to be an action of contiguous particles throughout, capable of propagation in curved lines, and to be concerned in all electrical phenomena; having in reality the character of a first, essential, and fundamental principle. . . It was formerly supposed that the electric fluid was confined to the surfaces of bodies by the mechanical pressure of the non-conducting air, in the midst of which all our experiments are carried on; but the fact is that the electric force, originally appearing at a certain place, is propagated to, and sustained at, a distance through the intervention of the contiguous particles of air, each of which becomes polarized, as in the case of insulated conducting masses, and appears in the inducteous body, *i.e.*, the body under induction as a force of the same kind exactly equal in amount, but opposite in its directions and tendencies."

VI. Electricity is found to reside on the surface of an insulated metallic conductor—a natural sequence of the polarization of particles. The difference in form, as between a ball and a point, so far as their relation to an electrical charge is concerned, is explicable by the theory of contiguous particles.

"It was," says Daniell, "by an apparatus constructed on similar principles to the electrophorus (p. 245) that Faraday brought to the test of experiment his theoretical anticipation that inductive action, taking place invariably through the intermediate influence of intervening matter, would be found to be exerted, not in the direction of straight lines only, as had always been assumed, but also in curved lines.

"A cylinder of solid shellac, of about 1 in. in diameter and 7 in. in length, was fixed in a wooden foot; it was made concave, and capped at its upper extremity, so that a brass ball or hemisphere could stand upon it. The upper half of the stem having been excited resinously, by friction with warm flannel, a brass ball was placed on the top, and then the whole arrangement examined by the carrier ball or proof-plane and Coulomb's electrometer (p. 229). For this purpose the carrier ball was applied to various parts of the ball; the two were uninsulated whilst in contact, or in position, then insulated, separated, and the charge of the carrier examined as to its nature and force. Of course, whatever general state the carrier acquired in any place where it was uninsulated and then insulated, it retained on removal from that place, and the distribution of the force upon the surface of the *inducteous* body while under the influence of the *inductive* was ascertained. The charges taken from the ball in this its uninsulated

state were always vitreous, or of the contrary character to the electricity of the lac. When the contact was made at the under part of the ball, the measured degree of force was 512°; when in a line with its equator, 270°; and when on the top of the ball, 130°."

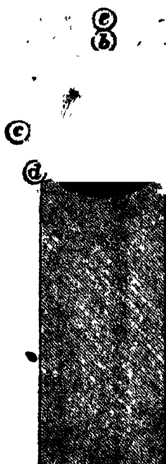


FIG. 258.—*Faraday's Experiment*, Proving that the polarization of the particles of air may occur in curved as well as in straight lines.

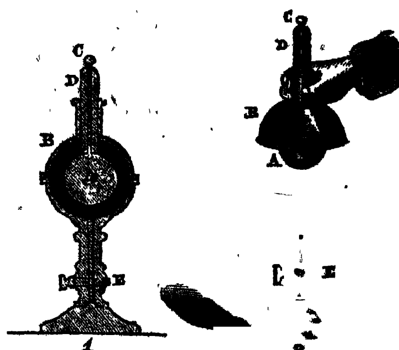


FIG. 259.—*Faraday's Apparatus for determining the specific or particular inductive power belonging to various substances.*

A, B, the two brass spheres, one within the other, A being supported by a brass wire, C, passing through a shellac rod, which latter insulates A, and prevents it communicating with B. The space between A and B can be filled with any solid, liquid, or gaseous dielectric. E, the stop-cock, which screws into the air-pump, if necessary.

The shellac electrophorus with its ball is here exhibited (Fig. 258), together with the positions of the carrier ball referred to. When placed at *d*, the effect produced was 512°; at *c*, 270°; at *b*, 130°. Even in the position *e* the proof or carrier ball became inducteous; and at *a* it was affected in the highest degree, and gave a result above 1000°.

VII. *Specific Induction.*—If one body capable of maintaining polarization can assume this condition quicker than another, it must be apparent that a resisting force of some kind exists, which causes insulating substances to vary in this respect.

Faraday ascertained this variable resistance by means of an apparatus (Fig. 259) consisting essentially of two brass spheres, placed one within the other, conducting communication between them being prevented by proper means. The intervening space between one sphere and another could then be filled with a variety of substances, solid, fluid, and gaseous.

Faraday used two of the instruments (Fig. 259), and a certain charge having been given to one of these, after the intervening space had been filled with the substance under investigation, it was connected with the second instrument, containing air; thus the latter became the standard of comparison used throughout the experiments; and the intensity, as before, was estimated by the carrier or proof

ball and Coulomb's electrometer. The inductive apparatus was in effect a Leyden jar, with the advantage that the dielectric, represented in the latter case by glass, could be removed at pleasure, and other bodies substituted. With this apparatus Faraday determined the inductive powers of a number of substances, and his experiments have been extended and verified by Sir William Snow Harris.

Substance.	Comparative Specific Inductive Power.
Air	1·00
Rosin	1·77
Pitch	1·80
Beeswax	1·86
Glass	1·90
Sulphur	1·93
Shellac	1·95

All gases, whatsoever may be their nature, have the same specific inductive power as air; no variation in the moisture, or temperature, or density of the gases affects the uniformity of their property in this respect.

VIII. Electricity stored in a Leyden jar can be measured into it, if necessary, by a beautiful contrivance of Harris, called the unit or standard jar; it is, of course, similar in principle to Lane's discharging electrometer, page 261. The unit Leyden jar is a very small one, and, mounted on a glass rod, the outside has a brass cap carrying a brass rod, which is placed at any required distance from the wire and ball coming from the interior of the miniature jar. According to the Franklinian experiment, page 251, every charge sent to the outside of the unit jar sets free from the inside an equivalent proportion of vitreous electricity; and directly the charge in the little jar is of sufficient intensity to break through the intervening thickness of air, it discharges itself with the usual snapping noise.

IX. With Harris's unit jar (Fig. 260) and balance, the following facts have been ascertained:

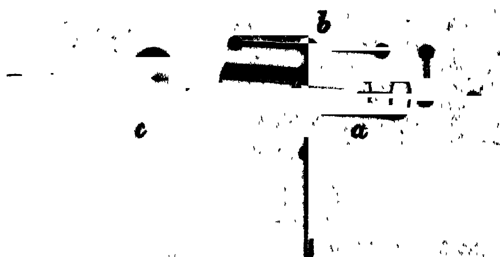


FIG. 260.—*Harris's Unit Jar.*

c, the conductor of the electrical machine connected with the outside of the unit jar; *b*, the inside, *a*, being connected with a large Leyden jar, every time the little jar discharges itself between *b* and *a*, a unit or definite quantity of electrical force has passed into the larger jar.

The area of the charged surface remaining constant, the attraction

between the two discs of the balance (see page 231) increases as the square of the quantity. The intensity of the charge being maintained at one fixed point, and the distance between the discs altered, the attractive force varies inversely as the square of the distance.

Coulomb's laws, already detailed, can only be regarded as general when they are confined to electrized molecules or points; they are again repeated here for the sake of the student, who may wish to remember the chief laws. First law, "Two electrized bodies attract and repel each other with a force which is inversely proportional to the square of the distance that separates them."

The force with which two bodies that possess different electricities attract each other is inversely proportional to the square of the distance by which they are separated.

X. The discharge of an electrical accumulation may take place in various ways; viz.,

1. By conduction,
2. By disruption,
3. By convection.

The first is the most simple, as when a brass rod is held in the hand, and laid upon the conductor of an electrical machine in full action.

The second involves the charge of particles, and their displace-

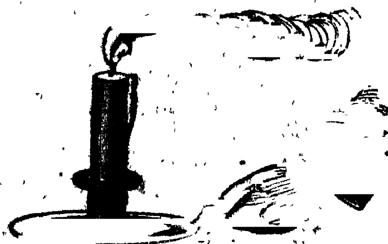


FIG. 261.—*A Current of Air set in motion from the Electric Point,*
And, by convection, carrying the electricity to the flame of the candle, when it is dissipated and lost by the heated and rarefied air.

ment in a gradual and steady manner, as by brushes or glow; or in a violent degree, as with a spark passing through the air, or causing the fracture of a thin Leyden jar, which has been too highly charged.

The third is special and peculiar, and involves motion; it is, therefore, called a "carrying discharge." Faraday illustrated it by insulating and electrifying a large copper boiler, 3 ft. in diameter, to a limit just within that which would produce the brush or moderate disruptive discharge. A brass ball, 2 in. in diameter, when suspended by a silk thread and held within 2 in. of the boiler, became charged, although insulated the whole time. As its electricity was contrary to that of the boiler, the effect would be, with a light ball, that it will be attracted, and then fly off to the nearest conductor, and

thus, like dust or any small particles capable of easy motion, would gradually, by convection, carry away the charge.

A brush discharge may be frequently changed to a glow, by s up a current of air in the same direction as that taken by the brush discharge; and this effect may be reversed, and a glow converted into a brush, by preventing the access of currents of air.

Lateral Discharge.

In consequence of the resistance offered, even by metals, to the progress of electricity, there is always a tendency in any electrical discharge to divide itself if there are many contiguous conductors in the same line or path; and thus sparks or flashes will occur when least expected, and, in the case of ships of war or powder-magazines, may do some harm if they are struck by lightning, although they may be supplied with lightning-conductors. The subject of *lateral discharge* received considerable attention from the late Sir William Snow Harris and Mr. Charles V. Walker, and the result of their discussions was the more careful protection of Her Majesty's ships by taking care to connect all masses or bars of metal with the main conductor, so that no accidental division shall occur anywhere; and thus all chance of flashes or sparks are prevented. The following experiment of Dr. Miller* serves to illustrate this point:

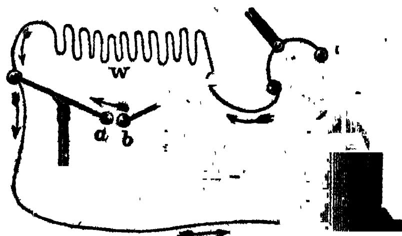


Fig. 262.

Charge a Leyden jar, and arrange a metallic wire, W, from 120 to 150 ft. in length, so as to act the part of discharger; at the same time open a short path for the discharge to the outer coating, by bringing the balls *a*, *b* within a short distance of each other. Under this arrangement a portion of the electricity takes the shorter course from *a* to *b*, and overcomes the high resistance of the stratum of air interposed between the balls, owing to the resistance experienced by the discharge to its passage along the continuous conducting wire W.

* Miller's "Elements of Chemistry," vol. i., p. 432.

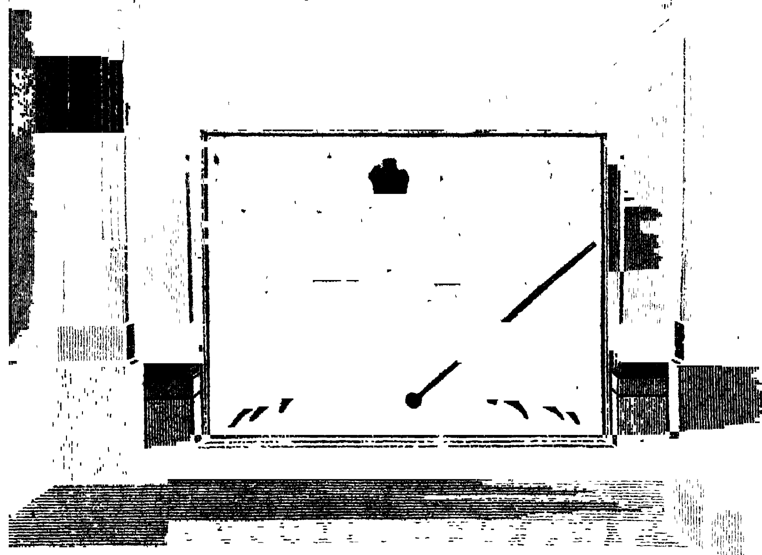


FIG. 263.—*Galvani's Experiment with the Nerves and Muscles of the dead Frog*

(As exhibited on the disc at the Polytechnic).

VOLTAIC, GALVANIC, OR DYNAMICAL ELECTRICITY.

It always seems quite natural, and taking things in their right order, to commence this subject by speaking of that famous illustration of animal electricity primarily discovered by Galvani, who ascertained that by touching the lumbar nerves of a frog, or lower part of the spine of a frog, recently killed, with a clean copper wire, and the muscles with a zinc wire, and then bringing the two metals in contact, that a current of electricity was evolved, which was instantly rendered evident by the frog-electroscope, the limbs being always convulsed in the most curious manner.

Galvani thought that the nerves and muscles of all animals were in oppo-

site states of electricity, and that the effect occurred only at the moment when the two opposite forces rush together and neutralize each other; but it was soon shown that the convulsions were due to the effect of a current of electricity, however feeble, set up when the two metals touched each other in the presence of a third element, viz., the liquid, containing chloride of sodium, with which the limbs of the recently killed frog would necessarily be moistened; it was, in short, the oxidation of the zinc wire that produced the current, and the prepared limbs of the frog represented only the electroscope that rendered the electrical disturbance evident.

The biographer of Lewis Galvani, in "Rees's Cyclopædia," states that he was born in 1737, at Bologna.

In his early youth he showed a great propensity to religious austerities; but being dissuaded from entering into an order of monks, whose convent he frequented, he directed his attention to the study of medicine. He pursued this study under able masters, and gained their esteem, especially that of Professor Galcazzi, who received him into his house and gave him his daughter in marriage. In the year 1762, after having sustained an inaugural thesis, "De Ossibus," he was appointed public lecturer in the University of Bologna and reader in anatomy to the Institute in that city. By the excellence of his method of teaching, he obtained crowded audiences.



FIG. 264.—*The prepared Frog's Limbs.*

Then follows the story of the soup made of frogs, which had been recommended to his dearly loved wife, who was in a declining state of health, and the accidental discovery that the limbs of the frog were affected by the point of a scalpel held near the prime conductor of an electrical machine in action.

Matteuchi, however, denies the *originality* of the experiment, and declares that it was performed many years before the time of Galvani, in the presence of the Grand Duke of Tuscany, by the celebrated Swammerdam.

His first publication on the subject was printed for the Institute at Bologna, 1791, and entitled "Aloysii Galvani de viribus Electricitatis in motu musculari Commentarius." This work immediately excited the attention of philosophers, both in Italy and other countries, and the experiments were repeated and extended.

In conjunction with his physiological inquiries, the duties of his professorship and his employment as a surgeon gave full occupation to the industry of Galvani. In addition to a number of curious observations on the organ of hearing in birds, which were published in the memoirs of the Institute of

Bologna, he drew up various memoirs on professional topics, which have remained unedited.

He regularly held learned conversations with a few literary friends, in which new works were read and commented upon. He was a man of a most amiable character in private life, and possessed of great sensibility, insomuch that the death of his wife, in 1790, threw him into a profound melancholy.

His early impressions on the subject of religion remained unimpaired; he was always punctual in practising its minutest rites; and from this cause, no doubt, he steadily refused to take the civic oath exacted by the then new constitution of the Cis-Alpine republic, and was consequently deprived of his posts and dignities. In a state of melancholy and poverty, he retired to the house of his brother James, a man of very respectable character, and fell into an extreme debility.

The republican governors, probably ashamed of their conduct towards such a man, passed a decree for his restoration to his professorial chair and its emoluments; but it was *too late*.

He expired on the 5th of November, 1798. But the good philosopher's name and works were not to lie dead and forgotten: his nephew, the Professor Aldini, of Bologna, seeing the grief and the sad end of his uncle, determined to rescue his name from obscurity, and to defend Galvani's theories, which had been attacked and repudiated.

For this purpose, Aldini travelled through France and England, demonstrating the remarkable physiological experiments of Galvani, and so pleased the professional authorities at Guy's Hospital, in 1803, that they presented him with a gold medal.

For a very complete epitome of organic electricity, the reader is referred to another work.* It may be sufficient here to state that Aldini maintained that

"Muscular contractions are excited by the development of a fluid (electric) in the animal machine, which is conducted from the nerves to the muscles, without the concurrence or action of metals.

"All animals are endowed with an inherent electricity, appropriate to their economy, which electricity, secreted by the brain, resides especially in the nerves, by which it is communicated to every part of the body.

"The principal reservoirs are the muscles, each of which he regarded to have two sides in opposite electric conditions.

"When a limb is willed to move, the nerves, aided by the brain, draw from the interior of the muscles some electricity; discharging this upon their surface, they are thus contracted and produce the required change of position."

It is a remarkable fact, that when an acid and an alkaline solution are so placed that their union may be effected through the substance of an animal membrane or, indeed, any other porous diaphragm, a current of electricity is evolved, the causes of which disturbance of electric equilibrium have already been investigated. Now, with the exception of the stomach and cæcum, the whole extent of the mucous membrane is, in the human subject, bathed with an alkaline mucous fluid, and the external covering of the body, the skin, is as constantly exhaling an acid fluid, except in the axillary and, perhaps, pubic regions. The mass of the animal frame is thus placed between two great

* "The Elements of Natural Philosophy," by Golding Bird, M.A., and Charles Brooke, M.A. John Churchill, New Burlington Street.

envelopes, the one alkaline and the other acid, meeting only at the external outlets. This arrangement has been shown by Donné to be quite competent to the evolution of electricity, and, accordingly, he found that if a platinum plate, connected with the galvanometer, be held in the mouth, whilst a second be pressed against the moist perspiring surface of the body, the needles will instantly traverse, as they did in the experiment just shown with an acid and an alkali.

The current thus detected by Donné at once explains the cause, and confirms the accuracy, of the celebrated experiment of Aldini, in which he excited convulsions in a frog by holding its foot in the moistened hand, and allowing the sciatic nerve to touch the tongue. There is also another remarkable experiment of Aldini, explicable on the same principle, and shown in Fig. 265.



FIG. 265.—*Aldini's Battery*,
Formed of the heads of recently decapitated oxen, A, B, C.

One of the ears of the first head, A, is well moistened with salt and water, and connected, through the tongue, by a silver wire with the ear of B; the tongue of B is in like manner connected with the ear of C.

The ear of A and the tip of the tongue of C form the terminals of this "bovine battery;" silver wires brought round from both are now connected with the prepared limbs of a frog, just killed, so that the portion of the spine still connected with its lumbar nerves touches the wire from the tip of the tongue, which had been previously drawn out of the mouth of the ox, and the skinned legs touch the wire from one of the ears. The frog's legs instantly contract, and the contraction ceases when the circuit is broken.

Dr. Wilkinson estimated that the irritable muscles of a frog's leg were no less than 56,000 times more delicate, as a test of electricity, than the most sensitive condensing electroscope (p. 243).

"About forty years prior to Galvani's discovery,* a person of the name of Sultzer gave an account of the following fact:

* "Rees's Cyclopædia," article Galvanism.

"If a piece of lead and a similar piece of silver be laid together, and the edges of both be brought in contact with the tongue, a taste is perceived similar to that of vitriol of iron; at the same time that the metals applied separately produce no effect.

"The observer of this fact does not appear to have been surprised at the effect. At that time *the doctrine of vibrations was employed to explain all natural phenomena.*

"He, therefore, concluded that some peculiar vibration took place from the contact of the metals, which produced the peculiar sensation on the tongue.

"All the world were satisfied with this explanation; and thus a prominent fact had slept in obscurity from the time of Sultzer to the time of Galvani."

The excitation of galvanic electricity is traceable to chemical action. It has already been stated that the combustion of a piece of charcoal will eliminate the electric force, and can be discovered by a delicate condensing electroscope. In galvanic experiments another instrument is required, in order to detect the feeble currents of electricity of low tension or intensity.

This instrument admits of wonderful refinement, as will be seen presently in the description of Sir William Thompson's reflecting galvanometer needle; but for ordinary experiments an instrument constructed as follows will suffice:

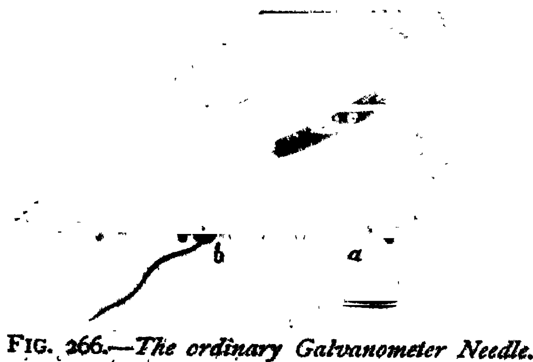


FIG. 266.—*The ordinary Galvanometer Needle.*

It will be seen presently, that a single wire conveying an electric current causes a magnetic needle to be deflected, and to take up a position at right angles to the current. If one wire can produce this result, it is clear that, by twisting the wire and increasing the number of convolutions, the effect of the single wire is multiplied; and by covering the wire with silk or cotton, so as to prevent lateral communication, a much greater surface of electrified wire is brought to bear by induction upon the magnetic needle. These conditions are fulfilled in Fig. 266, which will answer remarkably well for any ordinary lecture-table experiment; it consists of a magnetic needle, *c*, properly suspended and placed inside a coil of wire, *d*, the two ends of which terminate at *a b*. The whole is levelled by three screws.

The instrument, Fig. 267, is carefully levelled by three screws and spirit-levels; it contains a coil of fine wire, the two ends of which are brought out to two screw connections. The magnetic needle is made astatic (ἄστατος,

just balanced), by being connected with another magnetic needle, the north pole of which is placed opposite the south pole of the other, and *vice versâ*, and is thus unaffected by the earth's magnetism.

When a current of electricity, however feeble, is passed through the coil, the astatic needle is deflected according to laws which will be fully explained in the article on Electro-Magnetism.

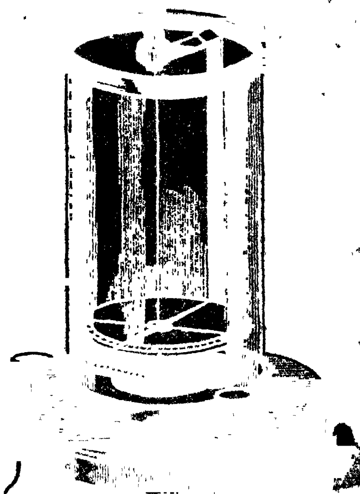


FIG. 267.—*The Galvanometer Multiplier.*

With this instrument the following experiments, all demonstrating that chemical action is a source of electricity, can be performed:

Into a small clean iron ladle, well scraped inside with a file to secure a metallic and not a rusted surface of iron, are placed some crystals of nitre; the ladle is supported by a tripod stand above a Bunsen's burner, and, when melted by the heat, a wire is wound round the clean metallic surface of the handle, and connected with one of the connecting screws of the galvanometer, and the other with a second wire, bound round a piece of hard charcoal, such as would be used for the electric lamp.

Of course all metallic connections must be bright and clean, and, directly the charcoal is dipped into the nitre, the oxidation of the charcoal occurs; the nitre gives oxygen to the charcoal, and converts it into carbonic acid, which unites with the remaining potash, producing carbonate of potash, and at the same moment a current of electricity is liberated, which violently affects the galvanometer needle.

The writer gives a drawing of the arrangement which will always be found most simple and effective at the lecture-table. Moreover, it illustrates another fact—that one of the elements of a voltaic series must be in a liquid state, if a notable current of dynamical electricity is desired to be shown or used. The writer has always felt that when coal or charcoal could be oxidized, and used



FIG. 268.—*The Oxidation of Carbon,*

An instance of the evolution of electricity by true chemical action. A, iron ladle, containing the nitre; B, the charcoal; C, the Bunsen burner; D, the galvanometer needle.

in the galvanic battery, the cheapest source of electricity will have been attained; and he learns from Mr. Crookes that a plate of platinum and one of charcoal placed in fused soda or potash give a very good current.

The same experiment repeated, and a condensing electroscope used as the test of electrical excitation, with the precaution of supporting the charcoal on a glass rod, is very satisfactory; and thus, by the oxidation and slow burning of charcoal, both current or dynamical electricity and static electricity may be obtained.

The usual mode of showing that charcoal in a state of combustion eliminates electricity is by twisting a piece of copper wire round a bit of charcoal some inches in length, and then connecting it with the lower plate of the condensing electroscope, whilst the upper plate is connected with the ground.

The charcoal is now ignited by a spirit-lamp, and if blown on with bellows, and the top plate of the electroscope raised and lowered several times, any rubbing of the two plates one against the other being carefully avoided, the gold leaves will be seen to diverge with negative electricity; and sometimes one movement of the upper plate of the condensing electroscope is found to be sufficient.

The experiments already quoted form a sort of connecting link between frictional and voltaic electricity, and are further supported by some excellent experiments of Faraday, who shows by a simple arrangement that the electricity of high tension obtained from the electrical machine will do all that a voltaic circuit may effect. Faraday says:*

"*Chemical Decomposition.*—The chemical action of voltaic electricity is characteristic of that agent, but not more characteristic than are the laws under which the bodies evolved by decomposition arrange themselves at the

* "Experimental Researches in Electricity" by Michael Faraday.

poles. Dr. Wollaston showed* that common electricity resembled it in these effects, and that "they are both essentially the same;' but he mingled with his proofs an experiment having a resemblance, and nothing more, to a case of voltaic decomposition, which, however, he himself partly distinguished; and this has been more frequently referred to by others, on the one hand, to prove the occurrence of electro-chemical decomposition, like that of the pile, and, on the other, to throw doubt upon the whole paper, than the more numerous and decisive experiments which he has detailed.

"I take the liberty of describing briefly my results, and of thus adding my testimony to that of Dr. Wollaston on the identity of voltaic and common electricity as to chemical action, not only that I may facilitate the repetition of the experiments, but also lead to some new consequences respecting electro-chemical decomposition.

"I first repeated Wollaston's fourth experiment,† in which the ends of coated silver wires are immersed in a drop of sulphate of copper. By passing the electricity of the machine through such an arrangement, that end in the drop which received the electricity became coated with metallic copper. One hundred turns of the machine produced an evident effect; two hundred turns a very sensible one. The decomposing action was, however, very feeble. Very little copper was precipitated, and no sensible trace of silver from the other pole appeared in the solution.

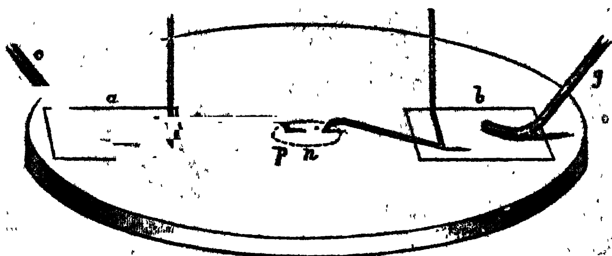


FIG. 269.

"A much more convenient and effectual arrangement for chemical decompositions by common electricity is the following:

"Upon a glass plate (Fig. 269) placed over, but raised above, a piece of white paper—so that shadows may not interfere—put two pieces of tinfoil, *a*, *b*; connect one of these by an insulated wire *c*, or wire and string, with the machine, and the other, *g*, with the discharging train, or the negative conductor; provide two pieces of fine platina wire, bent as in Fig. 270, so that the part *d f* shall be nearly upright, whilst the whole is resting on the three bearing points, *p*, *e*, *f*; place these as in Fig. 269; the points, *p*, *n*, then become the decomposing poles. In this way surfaces of contact, as minute as possible, can be obtained at pleasure, and the connection can be broken or renewed in a moment, and the substances acted upon examined with the utmost facility.

* "Philosophical Transactions," 1801, pp. 427, 434. † Ibid., 1801, p. 429.

"A coarse line was made on the glass with solution of sulphate of copper and the terminations *p* and *n* put into it; the foil, *a*, was connected with the positive conductor of the machine by wire and wet string, so that no sparks passed; twenty turns of the machine caused the precipitation of so much copper on the end, *p*, that it looked like copper wire; no apparent change took place at *n*.



FIG. 270.

"A mixture of half muriatic acid and half water was rendered deep blue by sulphate of indigo, and a large drop put on the glass (Fig. 269), so that *p* and *n* were immersed at opposite sides; a single turn of the machine showed bleaching effects round *p*, from evolved chlorine. After twenty revolutions no effect of the kind was visible at *n*; but so much chlorine had been set free at *p*, that when the drop was stirred the whole became colourless.

"A drop of solution of iodide of potassium mingled with starch was put into the same position at *p* and *n*; on turning the machine, iodine was evolved at *p*, but not at *n*.

"A still further improvement in this form of apparatus consists in wetting a piece of filtering paper in the solution to be experimented on, and placing that under the points *p* and *n*, on the glass; the paper retains the substance evolved at the point of evolution, by its whiteness renders any change of colour visible, and allows of the point of contact between it and the decomposing wires being contracted to the utmost degree. A piece of paper moistened in the solution of iodide of potassium and starch, or of the iodide alone, with certain precautions, is a most admirable test of electro-chemical action, and, when thus placed and acted upon by the electric current, will show iodine evolved at *p* by only half a turn of the machine. With these adjustments, and the use of iodide of potassium on paper, chemical action is sometimes a more delicate test of electrical currents than the galvanometer. Such cases occur when the bodies traversed by the current are bad conductors, or when the quantity of electricity evolved or transmitted in a given time is very small.

"A piece of litmus paper, moistened in solution of common salt or sulphate of soda, was quickly reddened at *p*. A similar piece, moistened in muriatic acid, was very soon bleached at *p*. No effects of a similar kind took place at *n*.

"A piece of turmeric paper, moistened in solution of sulphate of soda, was reddened at *n* by two or three turns of the machine, and in twenty or thirty turns plenty of alkali was there evolved. On turning the paper round, so that the spot came under *p*, and then working the machine, the alkali soon disappeared, the place became yellow, and a brown alkaline spot appeared in the new part under *n*.

"On combining a piece of litmus with a piece of turmeric paper, wetting both with solution of sulphate of soda, and putting the paper on the glass, so that *p* was on the litmus and *n* on the turmeric, a very few turns of the machine sufficed to show the evolution of acid at the former, and alkali at the latter, exactly in the manner effected by a volta-electric current.

"All these decompositions took place equally well, whether the electricity passed from the machine to the foil, *a*, through water or through wire only, by *contact* with the conductor or by *sparks* there, provided the sparks were not so large as to cause the electricity to pass in sparks from *p* to *n*, or towards *n*; and I have seen no reason to believe that, in cases of true electro-chemical decomposition by the machine, the electricity passed in sparks from the conductor, or at any part of the current, is able to do more, because of its tension, than that which is made to pass merely as a regular current.

"Finally, the experiment was extended into the following form, supplying in this case the fullest analogy between common and voltaic electricity:

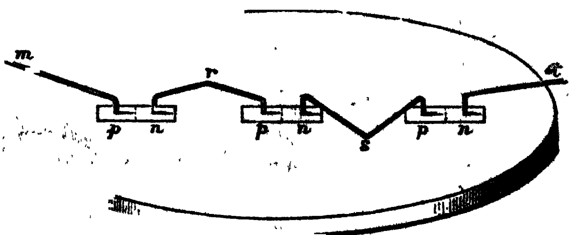


FIG. 271.

"Three compound pieces of litmus and turmeric paper were moistened in solution of sulphate of soda, and arranged on a plate of glass with platina wires, as in Fig. 271. The wire, *m*, was connected with the prime conductor of the machine, the wire, *t*, with the discharging train, and the wires, *r* and *s*, entered into the course of the electrical current by means of the pieces of moistened paper; they were so bent as to rest each on three points, *n*, *r*, *p*, *n*, *s*, *p*, the points, *r* and *s*, being supported by the glass, and the others by the papers; the three terminations, *p*, *p*, *p*, rested on the litmus, and the other three, *n*, *n*, *n*, on the turmeric paper. On working the machine for a short time only, acid was evolved at *all* the poles or terminations, *p*, *p*, *p*, by which the electricity entered the solution, an alkali at the other poles, *n*, *n*, *n*, by which the electricity left the solution.

"In all experiments of electro-chemical decomposition by the common machine and moistened papers, it is necessary to be aware of and to avoid the following important source of error:

"If a spark passes over moistened litmus and turmeric paper, the litmus paper (provided it be delicate, and not too alkaline) is reddened by it; and if several sparks are passed, it becomes powerfully reddened. If the electricity pass a little way from the wire over the surface of the moistened paper, before it finds mass and moisture enough to conduct it, then the reddening extends as far as the ramifications. If similar ramifications occur at the termination *n*, on the turmeric paper, they *prevent* the occurrence of the red spot due to

the alkali, which would otherwise collect there; sparks or ramifications from the points, *n*, will also redden litmus paper. If paper, moistened by a solution of iodide of potassium (which is an admirably delicate test of electro-chemical action), be exposed to the sparks or ramifications, or even a feeble stream of electricity through the air from either the point *p* or *n*, iodine will be immediately evolved.

"These effects must not be confounded with those due to the true electro-chemical powers of common electricity, and must be carefully avoided when the latter are to be observed. No sparks should be passed, therefore, in any part of the current, nor any increase of intensity allowed by which the electricity may be induced to pass between the platina wires and the moistened papers, otherwise than by conduction; for, if it burst through the air, the effect referred to ensues.

"The effect itself is due to the formation of nitric acid by the combination of the oxygen and nitrogen of the air, and is, in fact, only a delicate repetition of Cavendish's beautiful experiment. The acid so formed, through small in quantity, is in a high state of concentration as to water, and produces the consequent effects of reddening the litmus paper, or preventing the exhibition of alkali on the turmeric paper, or, by acting on the iodide of potassium, evolving iodine.

"By moistening a very small slip of litmus paper in solution of caustic potassa, and then passing the electric spark over its length in the air, I gradually neutralized the alkali, and ultimately rendered the paper red; on drying it, I found that nitrate of potassa had resulted from the operation, and that the paper had become touch-paper.

"Either litmus paper or white paper moistened in solution of iodide of potassium offers, therefore, a very simple, beautiful, and ready means of illustrating Cavendish's experiment of the formation of nitric acid from the atmosphere.

"I have already had occasion to refer to an experiment by Dr. Wollaston, which is insisted upon too much, both by those who oppose and those who agree with the accuracy of his views respecting the identity of voltaic and ordinary electricity. By covering fine wires with glass or other insulating substances, and then removingonly so much matter as to expose the point or a section of the wires, and by passing electricity through two such wires, the guarded points of which were immersed in water, Wollaston found that the water could be decomposed even by the current from the machine, without sparks, and that two streams of gas arose from the points, exactly resembling in appearance those produced by voltaic electricity, and, like the latter, giving a mixture of oxygen and hydrogen gases. But Dr. Wollaston himself points out that the effect is different from that of the voltaic pile, inasmuch as both oxygen and hydrogen are evolved from *each* pole; he calls it 'a very close *imitation* of the galvanic phenomena,' but adds, that 'in fact the resemblance is not complete,' and does not trust to it to establish the principles correctly laid down in his paper.

"This experiment is neither more nor less than a repetition, in a refined manner, of that made by Dr. Pearson, in 1797,* and previously by MM. Paets van Troostwyk and Deiman in 1789, or earlier. That the experiment should never be quoted as proving true electro-chemical decomposition is

* "Nicholson's Journal," 4to, vol. i., pp. 241, 299, 349.

sufficiently evident from the circumstance, that the law which regulates the transference and final place of the evolved bodies has no influence here. The water is decomposed at both poles independently of each other, and the oxygen and hydrogen evolved at the wires are the elements of the water existing the instant before in those places. That the poles, or rather points, have no mutual decomposing dependence may be shown by substituting a wire, or the finger, for one of them, a change which does not at all interfere with the other, though it stops all action at the changed pole. This fact may be observed by turning the machine for some time; for, though bubbles will rise from the point left unaltered, in quantity sufficient to cover entirely the wire used for the other communication, if they could be applied to it, yet not a single bubble will appear on that wire.

"When electro-chemical decomposition takes place, there is great reason to believe that the quantity of matter decomposed is not proportionate to the intensity, but to the quantity of electricity passed. Of this I shall be able to offer some proofs in a future part of this paper. But in the experiment under consideration this is not the case. If, with a constant pair of points, the electricity be passed from the machine in sparks, a certain proportion of gas is evolved; but, if the sparks be rendered shorter, less gas is evolved; and if no sparks be passed, there is scarcely a sensible portion of gases set free. On substituting solution of sulphate of soda for water, scarcely a sensible quantity of gas could be procured even with powerful sparks, and almost none with the mere current; yet the quantity of electricity in a given time was the same in all these cases.

"I do not intend to deny that with such an apparatus common electricity can decompose water in a manner analogous to that of the voltaic pile; I believe at present that it can. But when what I consider the true effect only was obtained, the quantity of gas given off was so small that I could not ascertain whether it was, as it ought to be, oxygen at one wire and hydrogen at the other. Of the two streams one seemed more copious than the other, and on turning the apparatus round, still the same side in relation to the machine gave the largest stream. On substituting solution of sulphate of soda for pure water, these minute streams were still observed; but the quantities were so small that on working the machine for half an hour I could not obtain at either pole a bubble of gas larger than a small grain of sand. If the conclusion which I have drawn relating to the amount of chemical action be correct, this ought to be the case.

"I have been the more anxious to assign the true value of this experiment as a test of electro-chemical action, because I shall have occasion to refer to it in cases of supposed chemical action by magneto-electric and other electric currents and elsewhere. But, independent of it, there cannot be now a doubt that Dr. Wollaston was right in his general conclusion, and that voltaic and common electricity have powers of chemical decomposition alike in their nature and governed by the same law of arrangement.

"*Physiological Effects.*—The power of the common electric current to shock and convulse the animal system, and when weak to affect the tongue and the eyes, may be considered as the same with the similar power of voltaic electricity, account being taken of the intensity of the one electricity and duration of the other. When a wet thread was interposed in the course of the current of common electricity from the battery charged by eight or ten revolutions of the machine in good action, and the discharge made by platina spatulas

through the tongue or the gums, the effect upon the tongue and eyes was exactly that of a feeble voltaic circuit.

"*Spark.*—The beautiful flash of light attending the discharge of common electricity is well known. It rivals in brilliancy, if it does not even very much surpass, the light from the discharge of voltaic electricity; but it endures for an instant only, and is attended by a sharp noise like that of a small explosion. Still no difficulty can arise in recognizing it to be the same spark as that from the voltaic battery, especially under certain circumstances. The eye cannot distinguish the difference between a voltaic and a common electricity spark, if they be taken between amalgamated surfaces of metal, at intervals only, and through the same distance of air."

The simple voltaic circuit may be variously modified, but usually consists of three elements, viz., two solids and one fluid, or one solid and two fluids. The first is well represented by a plate of copper, a plate of zinc, and some water acidulated with sulphuric acid; the second by a single plate of zinc, one half of which is immersed in salt and water, and the other in weak nitric acid.

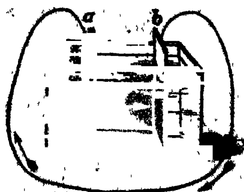


FIG. 272.—*A simple Voltaic Circuit, consisting of two Metals and one Fluid.*
a, zinc; *b*, copper. The liquid represents the acid, and the arrows show the direction of the current.

In the above figure it is seen that the zinc fulfils the part of the glass in the electrical machine; the acid, the rubber or excitant; the copper, the con-

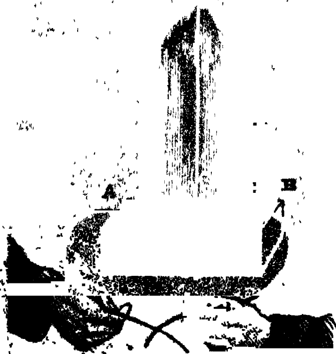


FIG. 273.—*Magnetic Needle, suspended over two Plates which are immersed in acid and water.*

ductor. By using a galvanometer, it is found that a current of + electricity flows from the zinc to the copper; and when the wires attached to the plates are brought in contact, this is called a closed circuit.

Every part of the circuit exercises an influence upon the magnetic needle. If a needle is suspended over the two plates (Fig. 273) lying in any convenient glass or porcelain dish, the needle, which should be arranged so that its direction is at right angles to the immersed plates, is then deflected parallel with them.

If we take one cell of a Cruikshank battery, we find a plate of zinc soldered to one of copper, these compound plates forming the sides of the cell, in which dilute acid is poured.

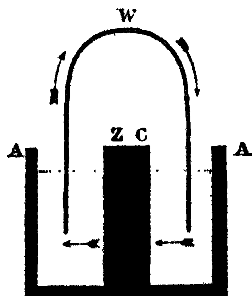


FIG. 274.

Z, C, zinc and copper, soldered together and cemented into a trough, A A. The current does not pass until a bent wire, W, connects the two sides containing the dilute sulphuric acid.

In Volta's crown of cups a simple voltaic circuit, formed of slips of zinc and copper, soldered together and placed alternately in separate glass vessels, represents another arrangement for producing the same result.

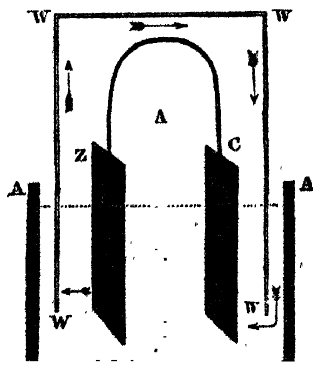


FIG. 275.

A A A, the trough, divided by a water-tight partition; Z, the zinc plate; C, the copper plate. The current circulates in the direction of the arrows when the wire, W W W W, is bent over and dips into the dilute acid.

A plate of zinc, inserted water-tight into a wooden trough, usually lined with

a cement made of rosin and tallow, filled on one side with a solution of common salt, and on the other with dilute nitric acid, gives a current if two wires are inserted on either side, but not touching the metal.

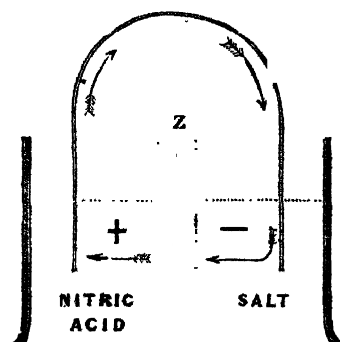


FIG. 276.—*Zinc Plate, cemented into a Mahogany Trough.*
The arrows show the direction of the current.

Or the arrangement may be varied by placing a long strip of clean copper in a cylindrical glass (Fig. 277); into this is poured dilute nitric acid until half the vessel is filled; then, with a tube and funnel, a strong solution of sulphate of copper is poured down to the bottom of the glass, which, gravitating by its weight, raises the weak nitric acid above it, and thus the copper is immersed in two solutions, the shaded one, A, being the solution of copper, and the one above it, B, the dilute nitric acid.

A wire, G, covered with gutta percha, but exposing an inch or two of the rim, is now let down quickly into the glass vessel, so that the gutta-percha covered portion passes through the upper stratum, and the exposed wire only is in contact with the solution of sulphate of copper.

An uncovered copper wire, H, is put into the dilute nitric acid; and when the ends of the two wires, G and H, are brought into metallic contact, a current circulates in the direction of the arrows, and for every atom of copper dissolved in B an equivalent proportion of the metal is deposited out of A on to the lower part of the copper plate, C C.

Professor Matteucci, of Pisa, has shown that dissected legs of frogs, so arranged that the half-thighs, skinned and laid alternately upon each other, the inner half touching the outer, and *vice versâ*, produce a current of electricity with which all the ordinary effects are produced, viz., deflection of galvanometer, decomposition of iodide of potassium, and divergence of the gold leaves of an electroscope. The electricity is that which belongs to the animal, and, as proved by Matteucci, circulates from the interior to the exterior of the muscle. He found that + electricity always circulates from the inside to the outside of the muscles of all animals, whether of birds, mammals, fishes, or cold-blooded reptiles.* Thus it is shown that metals may be dis-

* Matteucci has suggested that the true muscular fibre, which is oxidized, represents the zinc; the sarcolemma of the animal body, the platinum; whilst the exciting fluid is the blood.

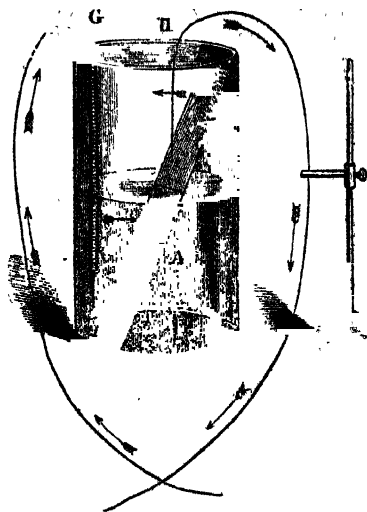


FIG. 277.

pensed with, and the exclamation ascribed to Napoleon I., by Chaptal, whilst looking at the action and power of his voltaic battery, derives additional force on reviewing the last-named fact. The remark of the august man was this:

"Voilà, docteur, l'image de la vie: la colonne vertébrale est le pile, la vessie le pôle positif, et le foie le pôle négatif."

Sir H. Davy endeavoured to protect the copper sheathing of vessels by attaching a metal which was more rapidly oxidized than the copper. His experiments appeared at first to be thoroughly successful, a bit of zinc as large as

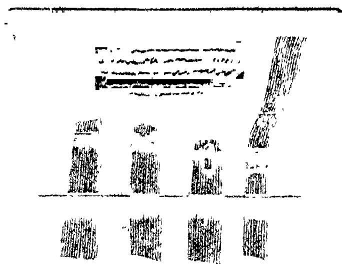


FIG. 278.—*Original Experiments of Sir H. Davy,*

Given to the late Professor Griffith by Davy, and passing to the writer, being pieces of copper and their protectors, arranged by Sir Humphrey Davy's own hands in his first experiments on the protection of copper sheathing.

a small-bore bullet being sufficient to protect a surface of copper 40 or 50 inches square; indeed, it may be said that Davy's experiments were *too* successful, for directly the action of the chlorides in the sea-water was stopped, and the

poisonous salt of copper no longer produced, the living things—the barnacles, the sea-weed, &c.—attached themselves, like Sinbad to the floating island, and, whilst making themselves uninvited passengers, they impeded the motion of the vessel by fouling its coppered sides.

The drawing, Fig. 278, represents the actual slips of copper, with bits of zinc tied round them with silk, used by Sir H. Davy in his first experiments.]

The principle of the action of the simple voltaic circle—zinc, copper, acid—is the use of dissimilar metals, one being acted upon more than the other.

The principle is so true, that a current may be obtained from two plates of zinc, provided they differ in their mechanical or chemical state. By melting zinc repeatedly and pouring it into cold water, a metal is obtained which is remarkably pure, and upon which dilute sulphuric acid acts very feebly.

If now a plate of this pure metal is made the opposite one to another of ordinary zinc, and the two connected with wires, a current is obtained, which distinctly deflects the galvanometer needle.

The writer, whilst making a great number of experiments on the probable effect of the water contained in the various docks on the copper sheathing of vessels, found that the plates of the sheathing lost weight, whilst the nail increased in weight in the exact proportion lost by the sheathing—as if the soft copper sheathing became the zinc element, and the harder pure copper nails the copper element.

The experiments were twenty in number, a bit of sheathing and a nail inserted through a hole in the metal being suspended by a silk thread in twenty different samples of London water. With hardly one exception, the sheathing lost weight, which the nail gained.

The writer's experiment with fused nitre and charcoal (p. 291) demonstrates that water can be entirely dispensed with, thus proving, as in Matteucci's experiments, that metals are not absolutely necessary. *Fluidity* of some kind is, however, indispensable to the production of current or dynamical electricity; and this fact conducts us to an assemblage of simple voltaic circles, or what is termed a voltaic pile or battery.

In 1819 a writer on Voltaism says:

"In the galvanic battery there appear to be two sources from which the electricity is obtained. The one is that which arises from the contact of the metals, and the other from the chemical action between the interposing fluid and the zinc surface. The first does not require even the presence of moisture, as is shown in the electric column of De Luc. The second is rendered greatly conspicuous by introducing between the opposite surfaces any substance capable of oxidating and dissolving the zinc."

It is well to mention here that Faraday has shown, by one of his simple and original experiments, that an electric current can be set up independent of all contact.

It consists of a piece of zinc, *b*, bent as in the figure, and a plate of platinum, *a*, to which is soldered a platinum wire. A little piece of bibulous paper is moistened with a solution of iodide of potassium and starch, and laid upon *b*. When the two metals are placed in

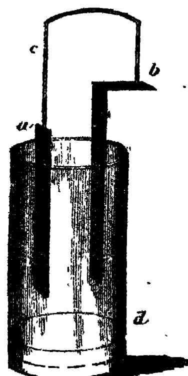


FIG. 279.

the glass vessel containing diluted sulphuric acid, and the end of the wire pressed upon it, iodine is liberated, which, uniting with the starch, produces a purple compound; and thus proves satisfactorily that a current of electricity has passed through the salt, and that true electro-chemical decomposition has taken place.

"Acids are the great promoters of the energy afforded by chemical action, because they dissolve the zinc after it has been oxidated by the oxygen of the water.

"This is more especially the case with the sulphuric and muriatic acids, because *these acids are not decomposed by the zinc.*

"The nitric acid produces a still greater galvanic effect, because the acid is decomposed and oxidates the zinc with greater facility than water.

"The water is also decomposed when this acid is used, and hydrogen is always evolved."

These views of the *rationale* of the action of the acids in the voltaic battery are substantially correct, although written forty-eight years ago.

The same writer * anticipates the porous material required in Daniell's and Grove's batteries; and, indeed, the more frequently we consult old works, the more difficult do we find it to disprove the words of Solomon, "There is nothing new under the sun." The writer remarks:

"When the fluids are required to be strictly separate, a bladder answers very well as a separating medium. Animal and vegetable substances, however, abound with so many elements that in nice experiments they would be objectionable. A vessel, divided into a proper number of cells, of *earthenware*, in the state of *biscuit*, would be best calculated for these experiments.

"This vessel should be made of pure silex and pure alumina.

"Should it ever become an object of manufacture to separate acids and alkalies from neutral salts, a vessel of wood, with a separation in the middle of *unglazed earthenware*, would answer very well."

Here we have porous cells anticipated distinctly.

The important discovery of accumulating the effects of single voltaic circles was made by Volta in 1800, and the first apparatus constructed with that view was called the voltaic pile.

The apparatus as first made by Volta (Fig. 280) consisted of a certain number of pairs of zinc and silver plates, separated from each other by pieces of wet cloth. Hence the arrangement was as follows:—zinc, silver, and wet cloth; zinc, silver, wet cloth, and so on. The silver plates were chiefly silver coins, the plates of zinc and the pieces of cloth being of the same size. He found this pile much more powerful when the pieces of cloth were moistened with a solution of common salt instead of pure water. A pile consisting of forty pairs of plates he found to possess the power of giving a very smart shock similar to that of an electric jar, and that this effect took place as often as a communication was made between each end of the pile, and as long as the pieces of cloth remained moist. An account of this discovery was communicated to the Royal Society, and published in the "Philosophical Transactions."

We do not hear of this celebrated philosopher making any further discovery after the invention of the pile and ascertaining the nature and extent of its effect upon animals.

Mr. Cruikshank improved upon Volta's apparatus by cementing the plates

* "Rees's Cyclopædia," article Voltaism.

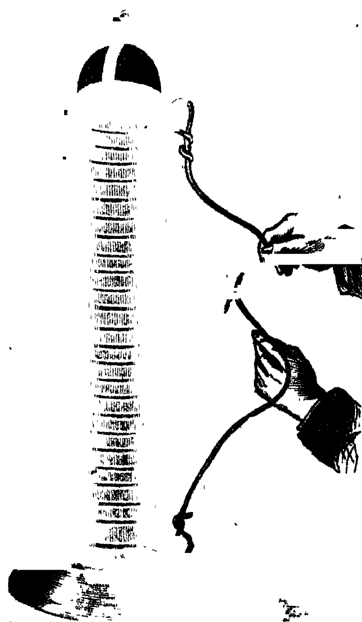


FIG. 280.—*The Voltaic Pile.*

of zinc and copper into a wooden box, which was then called the galvanic trough. In fact, the trough was Volta's pile placed horizontally, the cells being for the reception of the fluid to answer the purpose of pieces of wet cloth.

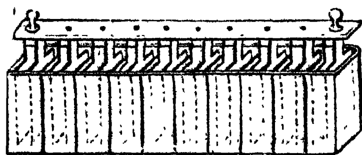


FIG. 281.—*Babington's improved Volta's "Couronne de Tasses."*
The plates lift in and out of the acid.

The learned Dr. Wollaston improved upon Cruikshank's arrangement by increasing the area of the conducting element, viz., the copper, by doubling this over the zinc; and, in fact, surrounding the latter with copper, he increased the power immensely. (Fig. 283.)

All his arrangements were so peculiarly neat and compact. An apparatus is sold at Elliott's (Fig. 282 A), called Wollaston's calorimeter, consisting of one pair of 4-in. zinc and double copper plates, movable in and out of a mahogany

trough. By this simple arrangement the calorific effect of an electric current is shown by the ignition of fine platinum wire, stretched between the terminals of the two metallic elements, zinc and copper.

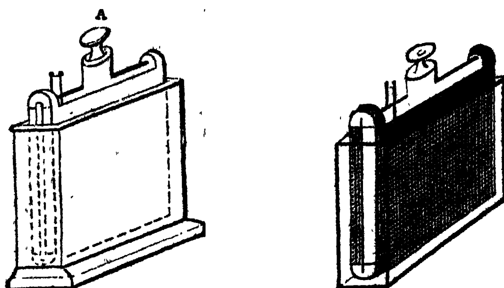


FIG. 282.

A, Wollaston's calorimeter; B, Grove's constant Wollaston wire-gauze calorimeter. The gauze facilitates the escape of hydrogen, and this form is more constant.

We now come to the first important change in the adjustment of the elements and the choice of fluids, which originated with the late Professor Daniell. In this work, the writer prefers that each author and inventor quoted here should speak for himself: the enthusiasm of an inventor supplies expressive language, which may be paraphrased, but can rarely be improved.*

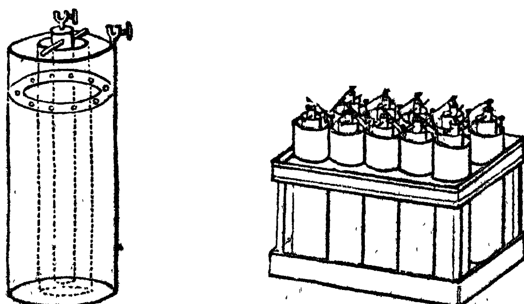


FIG. 283.

A, the single cell, Daniell's; B, a Daniell's battery.

"The liquid employed in the voltaic batteries, when it has been desired to excite them to the utmost, has generally been a mixture of sulphuric and nitric acids diluted with water, in which case much local action takes place from the zinc plates, which contributes nothing to the force which circulates, and which

* Daniell's "Introduction to Chemical Philosophy."

rapidly destroys them. Their power, moreover, speedily declines by the zinc which forms upon the copper plates; and they are very inconstant in their action. These defects are obviated in the construction of the constant battery, the contrivance of the author, which consists of a series of single circuits, constructed upon the principle of a central disposition of the active metal with regard to the conducting surface, as formerly explained. A cell of this battery consists of a cylinder of copper, 3½ in. in diameter, which experience has proved to afford the most advantageous distance between the generating and conducting surfaces, but which may vary in height according to the power which it is wished to obtain. A membraneous tube, formed of the gullet of an ox, is hung in the centre by a collar and circular copper plate, resting on the rim placed near the top of the cylinder; and in this is suspended, by a

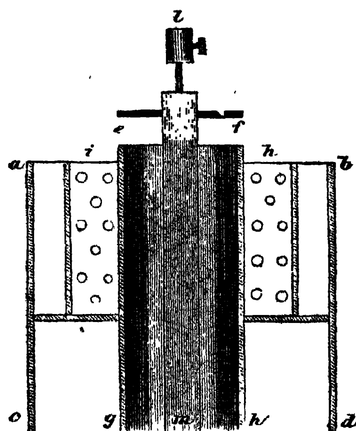


FIG. 284.

wooden cross-bar, a cylindrical rod of amalgamated zinc, half an inch in diameter. The cell is charged with a mixture of 8 parts of water to 1 part of oil of vitriol, which has been saturated with sulphate of copper, and portions of the solid salt are placed upon the upper copper plate, which is perforated like a colander, for the purpose of keeping the solution always in a state of saturation. The internal tube is filled with the same acid mixture, without the copper. A tube of porous earthenware may be substituted for the membrane, with great convenience, but probably with some loss of power. A number of such cells admit of being connected together very readily into a compound circuit, and will maintain a perfectly equal and steady current for many hours together, with a power far beyond that which can be produced by any other arrangement of a similar quantity of the same metals. The surface of the conducting metal is thus perpetually renewed by the deposition of pure copper, and the counteraction of zinc or any other precipitated metal effectually prevented. The minor affinity of the copper for the acid, however, still remains; and such an opposition could only be effectually avoided by the employment

of platinum plates, perpetually renewed by the decomposition in the circuit of chloride of platinum. Such an arrangement would be perfect, but too costly for ordinary applications.

"One of the cells of the constant battery is represented (Fig. 284). *a b c d* is a copper cylinder, in which is placed a smaller cylinder of porous earthenware. Upon the upper part of the copper cylinder rests a perforated colander, *h i*, through which the earthenware cylinder passes; *l m* is a cast rod of amalgamated zinc, resting upon the top of the interior cylinder by a cross-piece of wood, and forming the axis of the arrangement. The cell is charged by pouring into the earthenware cylinder water acidulated with one-eighth part of its bulk of oil of vitriol, the space between the earthenware tube and the copper being filled with the same acidulated water, saturated with sulphate of copper, and solid sulphate being placed in the colander. A number of such cells may be connected into a compound circuit by wires attached to the copper cylinders, and fastened to the zinc by clamps and screws, as shown below.

"A more powerful combination upon the same principle, though not so constant in its working or conveniently applicable to such extensive operations as that of the constant battery, has been contrived by Professor Gróves (Fig. 285), who makes use of conducting plates of platinum-foil, immersed in strong

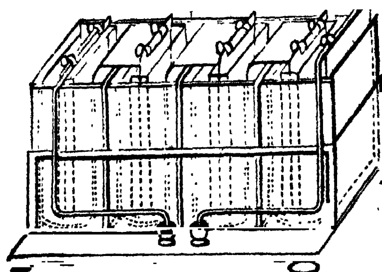


FIG. 285.—*A Groves's Battery.*

nitric acid, separated from the dilute sulphuric acid, in which the zinc is plunged, by a diaphragm of porous earthenware. The conducting power of the liquid portion of the combination is of the most perfect kind, and the hydrogen which travels in the circuit is immediately absorbed by the acid upon the conducting plate, and, reacting upon it, decomposes it with the evolution of copious fumes of nitrous gas. It has been already seen that a single cell of this construction is capable of overcoming the exterior resistance of a voltameter; and a very efficient series may thus be made with the bowls of tobacco-pipes and corresponding pieces of platinum-foil."

Mr. Warren De la Rue and Hugo Müller have invented another entirely new form of *constant* battery, which the authors recommend strongly * to the chemist and physicist. "As a ready source of dynamic electricity always at hand, and that especially when from a few hundreds to several thousand elements are requisite, it will be found to be valuable, handy, and compact. In

* "Journal of Chemical Society," November, 1868.

its construction no porous cell is needed, and the electrolyte is solid and very nearly insoluble, so that practically the electro-positive metal is scarcely attacked, even when the elements are left immersed with the electrodes disconnected for several weeks. In our battery the generating or electro-positive metal is zinc, which it is better to amalgamate, although it is not essential to do so; the negative metal is silver, and the electrolyte solid chloride of silver, the whole being immersed in a solution of chloride of sodium or chloride of zinc. The solution we generally use contains 25 grammes of common salt to a like quantity of distilled water (219 grains to a pint). It is not desirable to use common water for dissolving the chloride of sodium, as the carbonates present cause a cloudiness by precipitating the zinc as carbonate when the battery is in action. The form of the battery which we have adopted is represented in Figs. 286 and 287; but where a very large number of elements is wanted, it is more economical and convenient to employ a modification, presently to be described. The zinc element is formed of Belgian zinc wire (English zinc being too impure to be used advantageously), $2\frac{3}{8}$ in. (6 centimetres) long and 0·2 in. (5·1 mm.) diameter. The electro-negative element consists of a wire of pure silver 0·03 in. (0·77 mm.) in diameter, and round this is cast * a cylinder of chloride of silver, 0·22 in. (5·6 mm.) in diameter.

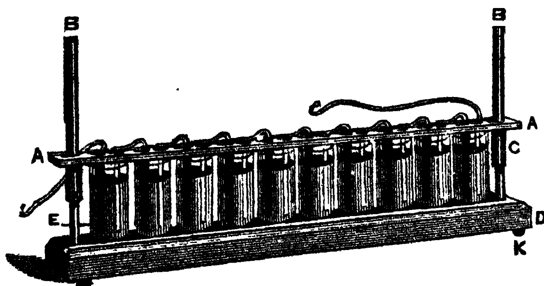


FIG. 286.

The silver wire projects about 0·2 in. (5 mm.) beyond the bottom end of the chloride of silver, and about $1\frac{1}{2}$ in. (3·8 centimetres) beyond the top end of it, so as to permit of its connection with the zinc of the next pair of elements. The cells are conveniently formed out of 1 oz. vials, by cutting off the necks by a diamond or an ignited splint-coal.

"The zinc and chloride of silver rods pass through, and are supported by, a lath or bar of varnished mahogany, A A, which is pierced for that purpose. The ends of this bar are also pierced with two larger holes, through which two supporting glass rods, B B, pass; it slides up and down these rods freely, and is retained in any required position by means of the vulcanized caoutchouc

* "In making these cylinders a mould which was designed for casting rods of lunar caustic (nitrate of silver) was found to be convenient. The mould contained a series of recesses which permitted of several rods being cast at a time. The silver wire was held firmly in the centre of the cylindrical recess by passing through a hole in the bottom of the mould, and by a series of arms projecting over the mouth of each recess at a sufficient distance to permit of the fused chloride being poured into them."

collars, C C, on which it rests; these grip the rods, B B, with adequate firmness to support the bar, but at the same time permit of its being moved up and down with sufficient freedom to immerse the element partially or wholly, as in Fig. 286, or to raise them entirely out of the liquid, as in Fig. 287. The raising is conveniently performed by placing the two forefingers of each hand under the collars, C C, and pressing the thumbs on the top of the glass rods, B B. The lowering of the bar can be effected by pressing down the two ends. These glass rods should not be varnished on that portion over which the vulcanized collars have to slide, as the varnish causes too much friction and a liability of jerking; below this point they may be varnished with advantage. They

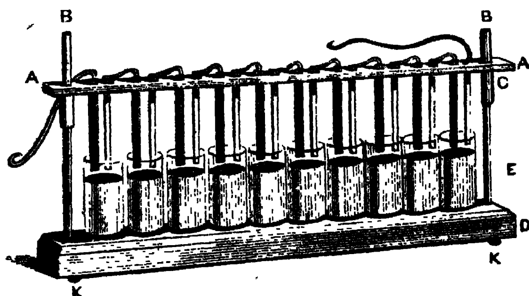


FIG. 287.

are cemented into the base of varnished mahogany, D D, in which is made a series of recesses to fit the cells, E, and keep them in their places. This base rests on feet of vulcanite to increase the insulation. The rods of zinc and chloride of silver are prevented from falling through the holes in bar A A by means of heads formed in the zinc by hammering the wire while it is held in a properly shaped tool, and on the chloride of silver by suitably shaping the upper end of the mould into which it is cast. A collar of caoutchouc is placed on the lower end of the zinc element to prevent contact between it and the rod of chloride of silver. Another plan of support is, however, more advantageous when a very numerous series of elements is used, as shown in Fig. 288, for it permits both of economizing the chloride of silver and of readily renewing it from time to time. Pieces of gutta percha or ebonite, I I, are well fitted into the bar A; they are pierced with a hole just large enough to permit of the silver wire, M, being drawn through them. The zincs are held in position by means of the vulcanized collars, N, while a second collar, O, serves as a clip for making connection with the silver wire, M, which is done by passing the wire between the zinc and the collar, O.

"It should be observed that, as the chloride of silver becomes reduced, the resulting spongy silver is of greater diameter and less regular in form than the original rods of chloride. It is evident, therefore, that the reduced silver cannot be withdrawn through the holes in the bar A A with the arrangement shown in Figs. 286 and 287; moreover, that portion of the chloride which remains out of the liquid in the arrangement (Figs. 286 and 287) is not reduced; and although no silver is ultimately lost, yet a portion of the useful effect of its chloride is sacrificed; and, consequently, the arrangement of Fig. 288 is both

more economical and convenient. When the chlorine is more or less completely exhausted by the reduction of the cylinders through their entire thickness, the resulting rods of spongy silver should be placed in a vessel of water acidulated with hydrochloric acid and some rods of zinc, in order to reduce

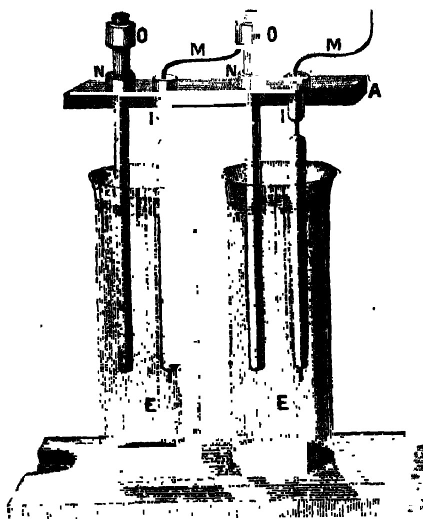


FIG. 288.

any undecomposed chloride, especially at their upper ends. After removal of the zinc, the spongy silver must be treated with dilute hydrochloric acid, and well washed to remove all traces of zinc. Very little, if any, loss of silver occurs, and the cost of renewal of the electrolyte is chiefly one of labour.

"There are many other forms of batteries. Professor Hare, of Philadelphia, devised an enormous calorimeter. Mr. Alfred Smee's battery, A, Fig. 289, is a most useful and popular form; it consists of a plate of silver, covered with black powder of platinum, and surrounded with amalgamated zinc. It is in form a reversed Wollaston battery. The conductor, the platinized silver, is placed inside, and the amalgamated zinc outside."

Sturgeon's battery, B, Fig. 289, is a cylindrical modification of Wollaston's battery. It consists of two copper cylinders brazed on to a foot, so as to form a hollow cylindrical vessel. Into this is placed a cylinder of zinc, which is made movable, so that the surface can be scraped and cleaned, or the whole cylinder renewed.

If amalgamated zinc is used, the mercury must be used sparingly, or else the excess will fall to the bottom of the copper cylindrical vessel, and, amalgamating the copper, will soon pass through the metal, rendering it so brittle that any hard substance, even the finger, may be thrust through it; indeed, very pure zinc cylinders should be used in preference to amalgamated zinc in this particular instance.

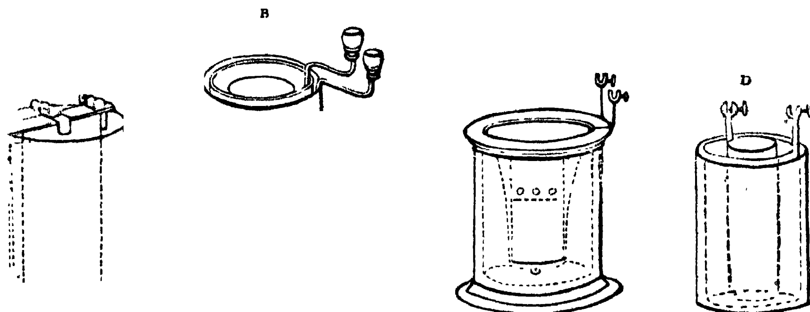


FIG. 289.
A, Smee's single cell; B, Sturgeon's cylindrical battery; C, Mullins's sustaining battery; D, Sturgeon's cast iron and amalgamated zinc battery.

C, Fig. 289, is a single cell of Mullins's sustaining battery. It consists of a narrow cylindrical slip of sheet zinc, surrounding a copper vessel closed at the bottom with wood, and a shelf provided at the top to carry crystals of the blue sulphate of copper. The copper vessel is enveloped with a membrane, and the whole arrangement placed in a stoneware jar. Sulphate of copper is used inside the membrane, and chloride of ammonium or dilute sulphuric acid outside the membrane. The title of sustaining battery is well maintained. The writer has seen them in use, and rough use too, and found that they gave a distinct current for months; always, of course, taking care that water is added, so that the salts do not dry up.

D, Fig. 289, Sturgeon's battery of cast iron and amalgamated rolled zinc. It consists of two cylinders, one of cast iron and the other of amalgamated zinc; they are placed one within the other, in dilute sulphuric acid, contained in a stoneware jar. This arrangement is well adapted for quantity effects; but its intensity is, of course, very low. This form is remarkably economical, and when made on the large scale is powerful.

All these batteries can be obtained from Messrs. Elliot, of Charing Cross, and the youthful student in looking at so many forms is apt to be puzzled with regard to selection, and naturally asks, Which is the best? The answer should be, What do you want to use the battery for? If you wish to make electrotypes, and to throw down silver or gold upon other surfaces by the voltaic current, you cannot select a cheaper, more convenient, and constant battery than that of Smee or, better still, Daniell. If the battery is required for the more brilliant effects, such as heating platinum wire, deflagrating the metals, and producing the electric light, there is no battery yet constructed which surpasses Professor Groves's for certainty and steadiness of results.

If you require a battery to work a small telegraphic system, or to move electro-magnetic machines, use a few cells of Smee, arranged on a bar of wood, and dropping into a trough made of stoneware and divided into cells, all of which contain dilute sulphuric acid (by making a stand and two uprights with pulleys, the metals can be drawn out by catgut cords and counterpoise weights at the sides when not in use, and immediately placed in position when required to perform the above-named work); or, still better, the improved bichromate battery, which is one of the best forms that can be em-



FIG. 290.

ployed: its advantages are freedom from smell, economy, and it is always ready for immediate use. Apps's patent battery is the best of all forms where the bichromate solution is used: the proportions are a saturated solution of bichromate of potash in water, with one-seventh part of sulphuric acid. A two-cell battery on this principle is shown in Fig. 290, and consists of two plates of zinc, surrounded by three plates of carbon, so arranged that the plates can be placed in, or out of, the bichromate solution.

DYNAMICAL ELECTRICAL PHENOMENA OBTAINED FROM THE VOLTAIC BATTERY.

The effects obtainable from the current of electricity flowing or in motion from pole to pole, and through the whole system of a voltaic battery, can be summed up under four heads:

1. Chemical phenomena—chemical action.
2. Calorific and lighting effects—heat and light.
3. Magnetic phenomena—magnetism.
4. Dynamical effects—mechanical motion.

As the action of a voltaic battery depends on "chemical action," it will be most interesting to commence the inquiry by speaking first of the chemical phenomena which may be rendered evident during the passage of a current of electricity through any given substance, the conditions of success being

first understood to be the fluidity of the matter under decomposition and its power of conducting the electric current.

"The first experiments," says a clear-headed writer in 1819, "made upon the pile in this country appear to have been made by Messrs. Nicholson and Carlisle. After observing the effects then already ascribed to the piles, on bringing the wires from each end of the column in contact with a drop of water, they observed a disengagement of bubbles of some elastic fluid; on close examination, they took the gas to be hydrogen. They then took a glass tube, about half an inch in diameter, into each end of which a cork was inserted, the tube being filled with water. Through each cork was introduced a brass wire, so that the ends of the wires in the glass were about 1¾ of an inch.

"The pile employed consisted of thirty-six half-crowns, and as many pieces of zinc and wet pasteboard. The zinc end of the pile was then connected with one of the wires in the tube, and the silver end to the other, so that the circuit formed by the wires was separated by the water in the tube placed between them. A stream of bubbles was observed at the end of the wire, in the tube connected with the silver end of the pile. No gas was disengaged from the opposite wire, but it speedily became tarnished, first of an orange colour and ultimately black. The tube was reversed, when it was observed that the wire which in the first experiment became black gave out bubbles, while that which previously gave out bubbles, in its turn, became tarnished. The emission of gas from the wire connected with the silver end of the pile was constant and uniform, except when a metallic current was formed between the ends of the pile, during which no gas whatever appeared. It was observed that when this metallic conductor was removed the appearance of the gas was not immediate, since there was an interval of two seconds between removing the wire and the appearance of the bubbles. After the process had continued two and a half hours, a bulk of gas was produced equal to two-thirds of a cubic inch. This gas was mixed with an equal bulk of common air, and exploded on the application of a lighted taper.

"These ingenious experimenters, supposing the phenomena to arise from the decomposition of the water, thought it surprising that the hydrogen should make its appearance at a distance of 1¾ in. from the point where the oxygen was disposed of. They made the experiment with a longer tube, but no appearance of gas was observed at the distance of 36 in. When they introduced an infusion of litmus, instead of pure water, they observed that the fluid in the vicinity of the wire connected with the zinc end of the pile became red, and hence were led to suppose that an acid was produced. The fluid at the other wire was not changed; but gas, as usual, was evolved. Mr. Nicholson ascertained that the zinc end of the pile was in the plus state of electricity, and the opposite end was in the minus state.

"They next varied the experiment by inserting in the tube of water wires of platina, instead of brass. Under these circumstances both the wires gave out gas, but neither of them was tarnished. There appeared to be a larger volume of gas from the silver end than from the zinc. The apparatus was so arranged that the gases were separately collected. On examination, the gas from the silver end was found to be hydrogen, as before, and that from the zinc end oxygen. Their proportions were found to agree with the component parts of water.

"The galvanic energy evinced in the decomposition of bodies was further

prosecuted by Mr. Cruikshank, of Woolwich; he employed in his experiments a pile consisting of from 40 to 100 pairs of plates of silver and zinc, about 1½ in. square. He also provided a glass tube, into each end of which was inserted a cork, one of which was closely cemented, so as to be air-tight. Through each of the corks a silver wire was passed, the ends in the tube being a certain distance from each other. The tube, being filled with water, was placed perpendicularly in a cup containing water, with the uncemented cork downwards. On the ends of the wires being connected with the ends of the pile, bubbles began to appear at the wire connected with the silver end of the pile; at the end of the other wire bubbles also appeared, and at the same time a white cloud, which became of a darker colour, and ultimately purple and black. The gas was collected, and found to consist of oxygen and hydrogen in the proportion of one to three. The wire from the zinc end of the pile was much corroded and even dissolved, which accounted for the deficiency of oxygen in the gaseous form. Mr. Cruikshank very truly conjectured that the cloud that became black was muriate of silver, the muriatic acid having been derived from some muriatic salt in the water employed.

"With a view to ascertain how far his conjecture was right, he filled the tube with distilled water, containing an infusion of litmus. The appearance with regard to the evolution of gas was similar to the last experiment; but the fluid in the vicinity of the wire coming from the zinc end of the pile became of a red colour, while the fluid about the other gradually lost its purple tinge and became of a deeper blue. In short, an acid appeared to be produced about the former wire, and an alkali about the latter. An infusion of Brazil wood underwent similar changes to those observed by an acid and an alkali.

"In all these experiments a quantity of silver was oxidated, and where water was employed a portion was always dissolved, some of which was precipitated at the wire from the silver end of the pile by the alkali which was produced. This ingenious experimenter, knowing that hydrogen in its nascent state was capable of reducing most metallic oxides, filled the tube with a solution of acetate of lead, and found that the hydrogen all disappeared, being employed in the reduction of the metal; by this means he also obtained pure oxygen gas. The same was observed when sulphate of copper and nitrate of silver were employed. When a solution of muriate of ammonia was employed in the tube, the silver became oxidated, the oxide combined with the muriatic acid of the salt, and the liquor afterwards smelt strongly of ammonia. In a similar way the muriate of soda and nitrate of magnesia were decomposed. Mr. Cruikshank repeated the above experiments; but, instead of silver wires, he inserted into the tubes gold wires. The proportion of oxygen gas was now much greater than with the silver wires, the gold not being susceptible of oxidation in the process.

"His next attempt was to collect the gas separately; this he effected by a tube about 10 in. long, which was bent into the form of the letter V; the wires were passed through corks firmly cemented into the ends of the tubes, coming near to the angular point. A small hole was made in the angular point of the tube, by which it was filled with water. The tube was then inverted in a cup of water, and the connection made with the other ends of the wires and the pile. By this contrivance the hydrogen gas ascended into one leg of the tube, and the oxygen into the other. He next filled the tube next employed, instead of water, with muriate of lime: the rapidity of the process was much increased; the gold wire on the zinc side became partly dissolved, and the fluid

in its vicinity assumed a yellow colour. When the tube was opened, a strong smell of aqua regia was perceived. Similar phenomena were observed when muriate of soda was employed. Many very anomalous facts were known in chemistry long previous to the discovery of galvanism. All those chemical phenomena under which the appearance called arborescence was observed were inexplicable till it was shown by some experiments, published in 'Nicholson's Journal' (vol. xv., p. 94), that galvanism is the cause of these singular phenomena. In the experiment where lead is so beautifully precipitated by suspending a piece of zinc in a solution of acetate of lead, the zinc first receives a small portion of lead, which with the lead forms a galvanic combination. The lead, if no solution of lead were present, would now give out hydrogen gas; but the hydrogen, instead of appearing in that form, combines with the oxygen of the oxide, and the metallic lead is formed at the same point. Hence the lead appears to grow from the last point formed, which gives the appearance of vegetation. That this effect does not depend upon the presence of zinc may be proved by the following experiment:

"Tie on one end of a glass tube, about half an inch wide, a piece of bladder, so that it may hold water, and fill it with a solution of acetate of lead; into the other end insert a cork loosely, and through the cork let a platina wire pass within about half an inch of the bladder. Into a wine-glass put some diluted muriatic acid, in which place a zinc wire. When the tube with the bladder is immersed in the wine-glass, if that part of the zinc wire that is without the glass be brought in contact with that part of the platina wire without the tube, beautiful crystals of metallic lead will appear upon the platina wire. If the acetate of lead be removed, and a dilute acid put in its place, bubbles of hydrogen will appear on the platina wire.

"Another experiment, similar to that of the lead tree, and equally anomalous, has been long known in chemistry. If a plate of glass be smeared over with a solution of nitrate of silver, and a brass pin or a piece of zinc wire be laid in the middle of the plate, beautiful ramifications of silver will soon appear as if growing out of the pin, very much resembling vegetation. By observing the process by a magnifying-glass, each branch of this arborescence may be seen to grow from the side or end of another, which proves that the silver forming the vegetative appearance is not reduced by the oxidable metal laid on the plate, but by something at the successive points of the silver branches. With a view to ascertain this fact, one half of the plate of glass should be smeared with nitrate of silver and the other half with dilute muriatic acid. If a piece of zinc wire be tied to a piece of platina wire, and the compound wire be so bent that the zinc may touch the dilute acid and the platina the nitrate of silver, the ramifications of silver will soon appear on the platina wire. That the silver is reduced by the hydrogen carried in the galvanic current is probable from varying the experiment as follows:

"If, instead of smearing the plate with nitrate of silver, the whole be covered with dilute acid, and the same compound arc be laid upon it, the platina will give out bubbles of hydrogen. In the common way of making this experiment with the pin, as well as the variation above stated, it appears that the process is kept up by the galvanic current which furnishes the hydrogen. The pin first reduces a small portion of silver, which forms a galvanic combination with the pin. The hydrogen, which, but for the presence of the remaining nitrate of silver, would appear in the gaseous form, is employed to deprive the silver of its oxygen. With the compound arc the zinc does not require to

touch the nitrate of silver, because the platina with the zinc is already a galvanic combination. The theory of whitening common pins can be explained only on this principle. The tin in a small proportion is dissolved in the tartrate of potash; pieces of metallic tin with the pins are also present. The two latter form the galvanic combination, and a portion of tin is reduced from the solution upon the pins, to which they owe their whiteness. We may generally conclude that, in all cases where one metal becomes the precipitant of another, the precipitation is much facilitated by the agency of the galvanic combination formed between the precipitating and the precipitated metals, and the consequent presence of hydrogen.

"If a piece of zinc be introduced into a solution of sulphate of copper, the zinc in the first instance becomes covered with copper, and the effect appears to stop. If, however, a very small excess of sulphuric acid be added, the process will go on with such rapidity that the copper becomes precipitated in a very short time. By minutely observing the process, the copper will be seen to be reduced upon that already produced, which is a proof that it is not done by the mere agency of zinc. It appears very evident that, when a galvanic combination of zinc with any lesser oxidable metal is placed in a dilute acid, a much larger quantity of hydrogen will be evolved from the lesser oxidable wire than could possibly be produced by any electrical intensity generated by the contact of the bodies employed; but that, independently of this, there is an immense quantity of electricity generated during the chemical action, by which the hydrogen is transported from the greater oxidable surface to the lesser one. If the quantity of hydrogen produced depended upon the attractions of the wires for the elements of the water, this power would depend upon the electrical intensity alone, and, of course, upon the series of the galvanic battery, whatever might be its surface; but it is found that the power of galvanism to decompose water is much increased by an increase of surface only."

Any clever experimentalist, reading this account carefully, would at once perceive that these experiments were capable of great extension, and, thus stimulated, his mind might pass, like that of Daniell and, later, of Warren De la Rue, to indicate the discovery of the electrotype, which Jacobi in Russia and Spenser in England brought before the scientific world, under the names of "Galvano-plastic" and "Electrography."

But it was left for the genius of Faraday to put "electro-chemical decomposition" in a clear light, and, in fact, to devise new instruments and a new nomenclature, which are set forth in the seventh series of his "Experimental Researches in Electricity:"—"On Electro-chemical Decomposition;" "On a new Measurer of Voltaic-electricity;" "On the Absolute Quantity of Electricity associated with the Particles or Atoms of Matter."

The simplicity of Faraday's diction, and the clearness with which he describes the phenomena observed, are most remarkable, and supply a "standard of excellence" which scientific writers may well try to imitate. The following are some of

"FARADAY'S RESEARCHES."

The theory which I believe to be a true expression of the facts of electro-chemical decomposition, and which I have therefore detailed in a former series of these Researches, is so much at variance with those previously advanced, that I find the greatest difficulty in stating results, as I think,

correctly, whilst limited to the use of terms which are current with a certain accepted meaning. Of this kind is the term pole, with its prefixes of positive and negative, and the attached ideas of attraction and repulsion. The general phraseology is, that the positive pole *attracts* oxygen, acids, &c., or, more cautiously, that it *determines* their evolution upon the surface; and that the negative pole acts in an equal manner upon hydrogen, conbustibles, metals, and bases. According to my view, the determining force is *not* at the poles, but *within* the decomposing body; and the oxygen and acids are rendered at the *negative* extremity of that body, whilst hydrogen, metals, &c., are evolved at the *positive* extremity.

To avoid, therefore, confusion and circumlocution, and for the sake of greater precision of expression than I can otherwise obtain, I have deliberately considered the subject with two friends, and, with their assistance and concurrence in framing them, I purpose henceforward using certain other terms, which I will now define. The poles, as they are usually called, are only the doors or ways by which the electric current passes into and out of the decomposing body; and they, of course, when in contact with that body, are the limits of its extent in the direction of the current. The term has been generally applied to the metal surfaces in contact with the decomposing substance; but whether philosophers generally would also apply it to the surfaces of air and water, against which I have effected electro-chemical decomposition, is subject to doubt. In place of the term pole, I propose using *electrode**, and I mean thereby that substance, or rather surface, whether of air, water, metal, or any other body, which bounds the extent of the decomposing matter in the direction of the electric current.

The surfaces at which, according to common phraseology, the electric current enters and leaves a decomposing body, are most important places of action, and require to be distinguished apart from the poles, with which they are mostly, and the electrodes, with which they are always, in contact. Wishing for a natural standard of electric direction to which I might refer these, expressive of their difference and at the same time free from all theory, I have thought it might be found in the earth. If the magnetism of the earth be due to electric currents passing round it, the latter must be in a constant direction, which, according to present usage of speech, would be from east to west, or, which will strengthen this help to the memory, that in which the sun appears to move. If in any case of electro-decomposition we consider the decomposing body as placed so that the current passing through it shall be in the same direction, and parallel to that supposed to exist in the earth, then the surfaces at which the electricity is passing into and out of the substance would have an invariable reference, and exhibit constantly the same relations of powers. Upon this notion we purpose calling that towards the east the *anode*†, and that towards the west the *cathode*‡; and whatever changes may take place in our views of the nature of electricity and electrical action, as they must affect the natural standard referred to in the same direction, and to an equal amount with any decomposing substances to which these terms may at any time be applied, there seems no reason to expect that they will lead to confusion, or tend in any way to support false views. The *anode* is therefore that surface

* ἤλεκτρον and ὁδος *a way*.

† ἀνα *upwards*, ὁδος *a way*; the way which the sun rises.

‡ κατα *downwards*, ὁδος *a way*; the way which the sun sets

at which the electric current, according to our present expression, enters; it is the negative extremity of the decomposing body; is where oxygen, chlorine, acids, &c., are evolved, and is against or opposite the positive electrode. The *cathode* is that surface at which the current leaves the decomposing body, and is its positive extremity; the combustible bodies, metals, alkalies, and bases, are evolved there, and it is in contact with the negative electrode.

I shall have occasion in these Researches, also, to class bodies together according to certain relations derived from their electrical actions; and wishing to express those relations without at the same time involving the expression of any hypothetical views, I intend using the following names and terms:—Many bodies are decomposed directly by the electric current, their elements being set free; these I propose to call *electrolytes**. Water, therefore, is an electrolyte. The bodies which, like nitric or sulphuric acids, are decomposed in a secondary manner are not included under this term. Then for *electro-chemically decomposed* I shall often use the term *electrolyzed*, derived in the same way, and implying that the body spoken of is separated into its components under the influence of electricity; it is analogous in its sense and sound to *analyze*, which is derived in a similar manner. The term *electrolytical* will be understood at once. Muriatic acid is electrolytical; boracic acid is not.

Finally, I require a term to express those bodies which can pass to the *electrodes*, or, as they are usually called, the poles. Substances are frequently spoken of as being *electro-negative* or *electro-positive*, according as they go under the supposed influence of a direct attraction to the positive or negative pole. But these terms are much too significant for the use to which I should have to put them; for though the meanings are perhaps right, they are only hypothetical, and may be wrong; and then, through a very imperceptible but still very dangerous, because continual, influence, they do great injury to science, by contracting and limiting the habitual views of those engaged in pursuing it. I propose to distinguish these bodies by calling those *anions*† which go to the *anode* of the decomposing body; and those passing to the *cathode*, *cations*‡; and when I have occasion to speak of these together, I shall call them *ions*. Thus, the chloride of lead is an *electrolyte*, and when *electrolyzed* evolves the two *ions*, chlorine and lead—the former being an *anion*, and the latter a *cation*.

These terms, being once well defined, will, I hope, in their use enable me to avoid much periphrasis and ambiguity of expression. I do not mean to press them into service more frequently than will be required, for I am fully aware that names are one thing and science another§.

It will be well understood that I am giving no opinion respecting the nature of the electric current now, beyond what I have done on a former occasion; and that though I speak of the current as proceeding from the parts which are positive to those which are negative, it is merely in accordance with the conventional, though in some degree tacit, agreement entered into by scientific men, that they may have a constant, certain, and definite means of referring to the direction of the forces of that current.

* ἤλεκτρον and λυω *solvo*. N. Electrolyte; V. Electrolyze.

† ἀνιον *that which goes up*. (Neuter participle.) ‡ κατιον *that which goes down*.

§ Since this paper was read, I have changed some of the terms which were first proposed, that I might employ only such as were at the same time simple in their nature, clear in their reference, and free from hypothesis.

ON A NEW MEASURER OF VOLTA-ELECTRICITY.

I have already said, when engaged in reducing common and voltaic electricity to one standard of measurement, and again when introducing my theory of electro-chemical decomposition, that the chemical decomposing action of a current *is constant for a constant quantity of electricity*, notwithstanding the greatest variations in its sources, in its intensity, in the size of the *electrodes* used, in the nature of the conductors (or non-conductors) through which it is passed, or in other circumstances. The conclusive proofs of the truth of these statements shall be given almost immediately.

I endeavoured upon this law to construct an instrument which should measure out the electricity passing through it, and which being interposed in

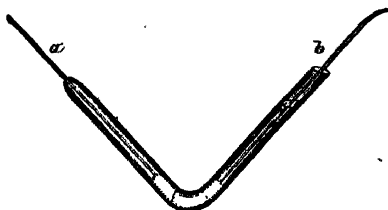


FIG. 292.



FIG. 291.

the course of the current used in any particular experiment, should serve, at pleasure, either as a *comparative standard* of effect or as a *positive measurer* of this subtile agent.

There is no substance better fitted, under ordinary circumstances, to be the indicating body in such an instrument than water; for it is decomposed with facility when rendered a better conductor by the addition of acids or salts; its elements may in numerous cases be obtained and collected without any embarrassment from secondary action, and, being gaseous, they are in the best physical condition for separation and measurement. Water, therefore, acidulated by sulphuric acid, is the substance I shall generally refer to, although it may become expedient in peculiar cases or forms of experiment to use other bodies.

The first precaution needful in the construction of the instrument was to avoid the recombination of the evolved gases, an effect which the positive electrode had been found so capable of producing. For this purpose various forms of decomposing apparatus were used. The first consisted of straight tubes, each containing a plate and wire of platina soldered together by gold, and fixed hermetically in the glass at the closed extremity of the tube (Fig. 291). The tubes were about 8 in. long, 0·7 of an inch in diameter, and graduated. The platina plates were about an inch long, as wide as the tubes

would permit, and adjusted as near to the mouths of the tubes as was consistent with the safe collection of the gases evolved. In certain cases, where it was required to evolve the elements upon as small a surface as possible, the metallic extremity, instead of being a plate, consisted of the wire bent into the form of a ring. When these tubes were used as measurers, they were filled with the dilute sulphuric acid, and inverted in a basin of the same liquid, being placed in an inclined position (Fig. 293 *a*), with their mouths near to each other, that as little decomposing matter should intervene as possible; and, also, in such a direction that the platina plates should be in vertical planes.

Another form of apparatus was that delineated (Fig. 292). The tube is bent in the middle; one end is closed; in that end is fixed a wire and plate, *a*, proceeding so far downwards, that, when in the position figured, it shall be as near to the angle as possible, consistently with the collection, at the closed extremity of the tube, of all the gas evolved against it. The plane of this plate is also perpendicular. The other metallic termination, *b*, is introduced at the time decomposition is to be effected, being brought as near the angle as possible, without causing any gas to pass from it towards the closed end of the instrument. The gas evolved against it is allowed to escape.

The third form of apparatus contains both electrodes in the same tube; the transmission, therefore, of the electricity, and the consequent decomposition, is far more rapid than in the separate tubes. The resulting gas is the sum of the portions evolved at the two electrodes, and the instrument is better

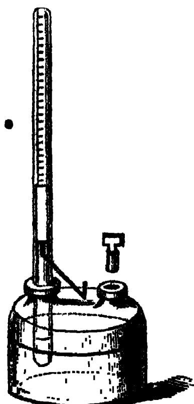


FIG. 293.

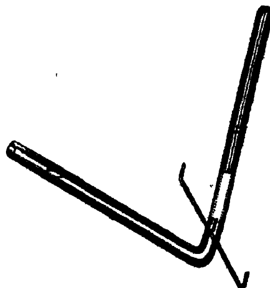


FIG. 294.

adapted than either of the former as a measurer of the quantity of voltaic electricity transmitted in ordinary cases. It consists of a straight tube (Fig. 293) closed at the upper extremity, and graduated, through the sides of which pass the platina wires (being fused into the glass), which are connected with two plates within. The tube is fitted by grinding into one mouth of a double-necked bottle. If the latter be one-half or two-thirds full of the dilute sulphuric acid, it will, upon inclination of the whole, flow into the tube and fill it. When an electric current is passed through the instrument, the gases evolved against the plates collect in the upper portion of the tube, and are not subject to the recombining power of the platina.

Another form of the instrument is given at Fig. 294.

A fifth form is delineated (Fig. 295 *b*). This I have found exceedingly useful in experiments continued in succession for days together, and where large quantities of indicating gas were to be collected. It is fixed on a weighted foot, and has the form of a small retort containing the two electrodes: the neck is narrow, and sufficiently long to deliver gas issuing from it into a jar placed in a small pneumatic trough. The electrode chamber, sealed hermetically at the part held in the stand, is 5 in. in length and 0·6 of an inch in diameter; the neck about 9 in. in length, and 0·4 of an inch in diameter internally. The figure will fully indicate the construction.

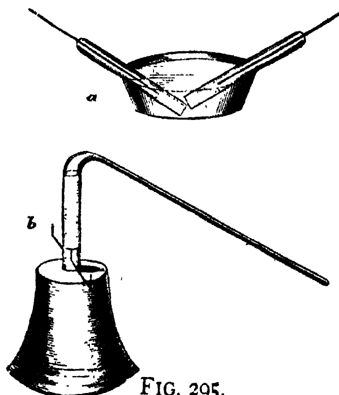


FIG. 295.

It can hardly be requisite to remark, that in the arrangement of any of these forms of apparatus, they, and the wires connecting them with the substance, which is collaterally subjected to the action of the same electric current, should be so far insulated as to ensure a certainty that all the electricity which passes through the one shall also be transmitted through the other.

The equivalent numbers do not profess to be exact, and are taken almost entirely from the chemical results of other philosophers in whom I could repose more confidence, as to these points, than in myself.

TABLE OF IONS.

Anions.

Oxygen	8	Phosphoric acid	35
Chlorine	35·5	Carbonic acid	22
Iodine	126	Boracic acid	24
Bromine	78·3	Acetic acid	51
Fluorine	18·7	Tartaric acid	66
Cyanogen	26	Citric acid	58
Sulphuric acid	40	Oxalic acid	36
Selenic acid	64	Sulphur (?)	16
Nitric acid	54	Selenium (?)	
[illegible] acid	75·5	Sulpho-cyanogen	

Cations.

Hydrogen	1	Mercury	200
Potassium	39·2	Silver	108
Sodium .	23·3	Platina	98·6?
Lithium .	10	Gold	(?)
Barium .	68·7		
Strontium	43·8	Ammonia . . .	17
Calcium	20·5	Potassa	47·2
Magnesium	12·7	Soda	31·3
Manganese	27·7	Lithia	18
Zinc .	32·5	Baryta	76·7
Tin .	57·9	Strontia . . .	51·8
Lead .	103·5	Lime	28·5
Iron .	28	Magnesia . . .	20·7
Copper .	31·6	Alumina . . .	(?)
Cadmium	55·8	Protoxides generally.	
Cerium .	46	Quinia	171·6
Cobalt .	29·5	Cinchona . . .	160
Nickel .	29·5	Morphia . . .	290
Antimony	64·6?	Vegeto-alkalies generally.	
Bismuth	71		

Now it is wonderful to observe how small a quantity of a compound body is decomposed by a certain portion of electricity. Let us, for instance, consider this and a few other points in relation to water. *One grain* of water, acidulated to facilitate conduction, will require an electric current to be continued for three minutes and three-quarters of time to effect its decomposition, which current must be powerful enough to retain a platina wire, 1-104th of an inch in thickness*, red hot, in the air during the whole time; and if interrupted anywhere by charcoal points, will produce a very brilliant and constant star of light. If attention be paid to the instantaneous discharge of electricity of tension, as illustrated in the beautiful experiments of Mr. Wheatstone†, and to what I have said elsewhere on the relation of common and voltaic electricity, it will not be too much to say, that this necessary quantity of electricity is equal to a very powerful flash of lightning. Yet we have it under perfect command; can evolve, direct, and employ it at pleasure; and when it has performed its full work of electrolyzation, it has only separated the elements of a single grain of water.

I showed in a former series of these Researches on the relation by measure of common and voltaic electricity, that two wires, one of platina and one of zinc, each 1-18th of an inch in diameter, placed 5-16ths of an inch apart,

* I have not stated the length of wire used, because I find by experiment, as would be expected in theory, that it is indifferent The same quantity of electricity which, passed in a given time, can heat an inch of platina wire of a certain diameter red hot, can also heat a hundred, a thousand, or any length of th[illegible] ...me degree, provided the cooling circumstances are the same for every part in [illegible] proved by the volta-electrometer. I found that, whether half-an-inch or 8 in[illegible] ...stant temperature of dull redness, equal quantities of water were decomposed [illegible] cases. When the half-inch was used, only the centre portion of wire was [illegible] ...y even be used as a rough but ready regulator of a voltaic current; for if it be [illegible] ...t, and the larger wires communicating with it be shifted nearer to or further [illegible] ...e portion of wire in the circuit sensibly at the same temperature, the current will be nearly uniform.

† [illegible] ...on Gazette," 1833, March 1 and 8; "Philosophical Magazine," 1833, p. 204; "L'Institute," [illegible]

and immersed to the depth of 5-8ths of an inch in acid, consisting of one drop of oil of vitriol and 4 oz. of distilled water, at a temperature of about 60° Fahr., and connected at the other extremities by a copper wire 18 ft. long and 1-18th of an inch in thickness, yielded as much electricity in little more than three seconds of time as a Leyden battery charged by thirty turns of a very large and powerful plate electric machine in full action. This quantity, though sufficient if passed at once through the head of a rat or a cat to have killed it, as by a flash of lightning, was evolved by the mutual action of so small a portion of the zinc wire and water in contact with it, that the loss of weight sustained by either would be inappreciable by our most delicate instruments; and as to the water which could be decomposed by that current, it must have been insensible in quantity, for no trace of hydrogen appeared upon the surface of the platina during those three seconds.

What an enormous quantity of electricity, therefore, is required for the decomposition of a single grain of water! We have already seen that it must be in quantity sufficient to sustain a platina wire 1-104th of an inch in thickness, red hot, in contact with the air for three minutes and three-quarters, a quantity which is almost infinitely greater than that which could be evolved by the little standard voltaic arrangement to which I have just referred. I have endeavoured to make a comparison by the loss of weight of such a wire in a given time in such an acid, according to a principle and experiment to be almost immediately described; but the proportion is so high, that I am almost afraid to mention it. It would appear that 800,000 such charges of the Leyden battery as I have referred to above would be necessary to supply electricity sufficient to decompose a single grain of water; or, if I am right, to equal the quantity of electricity which is naturally associated with the elements of that grain of water, endowing them with their mutual chemical affinity.

In further proof of this high electric condition of the particles of matter, and the *identity, as to quantity, of that belonging to them with that necessary for their separation*, I will describe an experiment of great simplicity, but extreme beauty, when viewed in relation to the evolution of an electric current and its decomposing powers.

A dilute sulphuric acid, made by adding about one part by measure of oil of vitriol to thirty parts of water, will act energetically upon a piece of plate zinc in its ordinary and simple state; but, as Mr. Sturgeon has shown*, not at all, or scarcely so, if the surface of the metal has in the first instance been amalgamated; yet the amalgamated zinc will act powerfully with platina as an electromotor, hydrogen being evolved on the surface of the latter metal, as the zinc is oxidized and dissolved. The amalgamation is best effected by sprinkling a few drops of mercury upon the surface of the zinc, the latter being moistened with the dilute acid, and rubbing with the fingers so as to extend the liquid metal over the whole of the surface. Any mercury in excess, forming liquid drops upon the zinc, should be wiped off†.

Two plates of zinc thus amalgamated were dried and accurately weighed: one, which we will call A, weighed 163·1 grains; the other, to be called B, weighed 148·3 grains. They were about 5 in. long, and 0·4 of an inch wide.

* "Recent Experimental Researches," &c., 1830, p. 74, &c.

† The experiment may be made with pure zinc, which, as chemists well know, is but slightly acted upon by dilute sulphuric acid, in comparison with ordinary zinc, which during the action is subject to an infinity of voltaic actions. See De la Rive on this subject, "Bibliothèque Universelle," 1830, p. 391.

An earthenware pneumatic trough was filled with dilute sulphuric acid, of the strength just described, and a gas jar, also filled with the acid, inverted in it*. A plate of platina of nearly the same length, but about three times as wide as the zinc plates, was put up into this jar. The zinc plate A was also introduced into the jar, and brought in contact with the platina, and at the same moment the plate B was put into the acid of the trough, but out of contact with other metallic matter.

Strong action immediately occurred in the jar upon the contact of the zinc and platina plates. Hydrogen gas rose from the platina, and was collected in the jar; but no hydrogen or other gas rose from *either* zinc plate. In about ten or twelve minutes, sufficient hydrogen having been collected, the experiment was stopped: during its progress a few small bubbles had appeared upon plate B, but none upon plate A. The plates were washed in distilled water, dried, and reweighed. Plate B weighed 148·3 grains, as before, having lost nothing by the direct chemical action of the acid. Plate A weighed 154·65 grains, 8·45 grains of it having been oxidized and dissolved during the experiment.

The hydrogen gas was next transferred to a water-trough and measured; it amounted to 12·5 cubic inches, the temperature being 52°, and the barometer 29·2 inches. This quantity, corrected for temperature, pressure, and moisture, becomes 12·15453 cubic inches of dry hydrogen at mean temperature and pressure, which, increased by one-half for the oxygen that must have gone to the *anode*, i.e. to the zinc, gives 18·232 cubic inches as the quantity of oxygen and hydrogen evolved from the water decomposed by the electric current. According to the estimate of the weight of the mixed gas before adopted, this volume is equal to 2·3535544 grains, which therefore is the weight of water decomposed; and this quantity is to 8·45, the quantity of zinc oxidized, as 9 is to 32·31. Now taking 9 as the equivalent number of water, the number 32·5 is given as the equivalent number of zinc—a coincidence sufficiently near to show, what indeed could not but happen, that for an equivalent of zinc oxidized an equivalent of water must be decomposed†.

But let us observe *how* the water is decomposed. It is electrolyzed, *i.e.*, is decomposed voltaically, and not in the ordinary manner (as to appearance) of chemical decompositions; for the oxygen appears at the *anode* and the hydrogen at the *cathode* of the decomposing body, and these were in many parts of the experiment above an inch asunder. Again, the ordinary chemical affinity was not enough under the circumstances to effect the decomposition of the water, as was abundantly proved by the inaction on plate B; the voltaic current was essential. And to prevent any idea that the chemical affinity was almost sufficient to decompose the water, and that a smaller current of electricity might, under the circumstances, cause the hydrogen to pass to the *cathode*, I need only refer to the results which I have given to show that the chemical action at the electrodes has not the slightest influence over the *quantities* of water or other substances decomposed between them, but that they are entirely dependent upon the quantity of electricity which passes.

What, then, follows as a necessary consequence of the whole experiment? Why, this—that the chemical action upon 32·31 parts, or one equivalent of

* The acid was left during a night with a small piece of unamalgamated zinc in it, for the purpose of evolving such air as might be inclined to separate, and bringing the whole into a constant state.

† The experiment was repeated several times with the same results.

zinc, in this simple voltaic circle, was able to evolve such quantity of electricity in the form of a current as, passing through water, should decompose 9 parts, or one equivalent of that substance; and, considering the definite relations of electricity as developed in the preceding parts of the present paper, the results prove that the quantity of electricity which, being naturally associated with the particles of matter, gives them their combining power, is able, when thrown into a current, to separate those particles from their state of combination; or, in other words, that *the electricity which decomposes, and that which is evolved by the decomposition of, a certain quantity of matter are alike.*

But admitting that chemical action is the source of electricity, what an infinitely small fraction of that which is active do we obtain and employ in our voltaic batteries! Zinc and platina wires, 1-18th of an inch in diameter and about half an inch long, dipped into dilute sulphuric acid, so weak that it is not sensibly sour to the tongue, or scarcely to our most delicate test-papers, will evolve more electricity in 1-20th of a minute than any man would willingly allow to pass through his body at once. The chemical action of a grain of water upon four grains of zinc can evolve electricity equal in quantity to that of a powerful thunder-storm. Nor is it merely true that the quantity is active; it can be directed and made to perform its full equivalent duty. Is there not, then, great reason to hope and believe that, by a closer *experimental* investigation of the principles which govern the development and action of this subtile agent, we shall be able to increase the power of our batteries, or invent new instruments which shall a thousandfold surpass in energy those which we at present possess?

After Faraday had invented his first apparatus or volta-measurer, other and more convenient contrivances were made by himself and others.

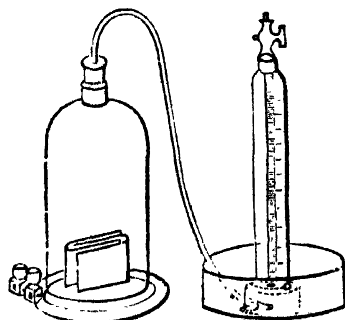


FIG. 296.—*Large Voltameter for measuring the quantity of Mixed Gases obtainable from small or large batteries.*

The apparatus made by Elliott Brothers consists of a large pair of platina-plate electrodes, doubly folded and approximated one to the other, so as to present the largest amount of surface for the liberation of the mixed gases, oxygen and hydrogen; the plates are contained in a glass bell jar, surmounted by a bent conducting tube to convey the gases to the graduated cylindrical glass jar, which is provided with a stop-cock.

Faraday's voltameter experiment has been reversed in the most philosophical manner by Professor Grove, who partly filled fifty tubes alternately with oxygen and hydrogen. The tubes each contained a plate of platinum roughened with a deposit of black platinum powder upon them, and, when connected as in Fig. 297, they produced a current which afforded all the ordinary electrical results. The tubes are partly filled with, and stand in glass jars containing, dilute sulphuric acid, specific gravity 1·200, and, when placed on a stool supported on glass legs, give a shock which can be felt by five persons,

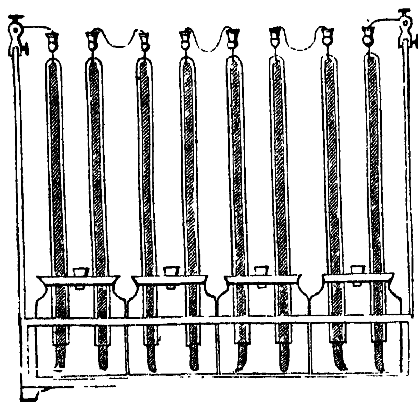


FIG. 297.—*Grove's Gas Battery.*

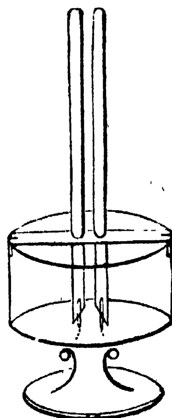


FIG. 298.

affected the electroscope and the galvanometer needle, gave an electric spark, and decomposed water, iodide of potassium, &c. This beautiful experiment proved that just as the current of electricity decomposed water into oxygen and hydrogen (Fig. 298), so the same gases properly disposed, as in Fig. 299, would reunite, and, in the act of reunion, evolve a current of electricity that would again repeat itself in the production of all those phenomena already detailed

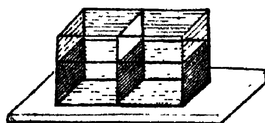


FIG. 299.—*Glass Cell with cardboard Diaphragm for Chemical Decomposition.*

When the poles of the battery, usually platinum plates, are immersed in a glass cell, divided in the centre with a slip of card, and filled with a solution of iodide of potassium and starch, electrolytic decomposition occurs; the iodine is liberated on one side, and, combining with the starch, produces a purple colour, whilst the other side remains colourless because the alkali is there liberated and has no action upon the starch. If, however, a little tincture of turmeric is carefully dropped in and mixed, it turns a reddish brown,

and thus indicates the presence of the potassium oxidized and changed to potash in the presence of water.

A number of amusing chemical decompositions may be performed with the same arrangement. A very good one is that in which a solution of common salt and indigo is used. The liberation of chlorine at one pole causes the half of the contents of the trough to be bleached, the other remaining a blue colour.

When iodide of potassium or chloride of sodium yield their elements to the power of the circulating electricity, such and other similar cases are called "*primary* results." But when metals are reduced, as already mentioned, the nascent hydrogen and the oxide of the metal are deposited together, and the former, reacting on the latter, deoxidizes the oxide, and reduces it to the metallic state. It is thus we have the art of electrotyping, already alluded to at page 313, and such a decomposition would be called a "*secondary* result."

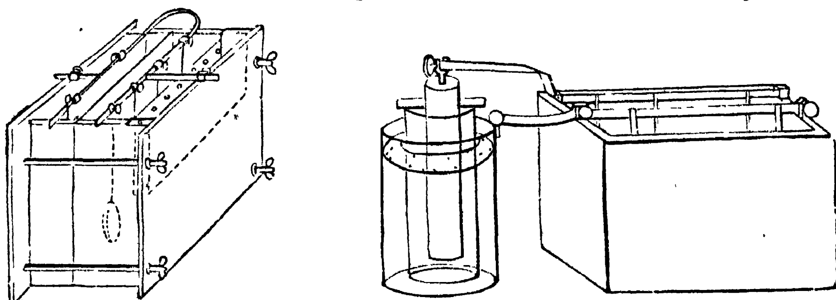


FIG. 300.

The above are two arrangements of a Daniell's single cell and trough, containing the solution of sulphate of copper and the various seals, casts, &c., which are to be copied by the deposit of metallic copper upon them. In one, the Daniell's cell is connected with a trough; in the other, the cell itself, zinc, acid, and the medals to be copied in the sulphate of copper, perform the same functions.

OHM'S LAW.

In the admirable and exhaustive work on the electric telegraph, Mr. Robert Sabine says:

"Until the end of the first quarter of the present century, physicists were still in darkness as to the mode and laws of the propagation of the galvanic current. The immense velocity with which the galvanic impulse is transmitted led to the seeking an analogy between it and light, and on this wrong scent much time and labour was lost; when Ohm, a German physicist, conceived the happy idea that a juster analogy was to be found in the propagation of heat, and proceeded to apply to galvanic electricity the formulæ of Fourrier and Poisson. He expressed the intensity of an electric current as directly proportional to the electro-motive force, and inversely to the resistance of the circuit. Algebraically, if E is the electro-motive force, R the resistance, and I the intensity,

$$I = \frac{E}{R} \quad . \quad . \quad . \quad . \quad . \quad (1.$$

"Of these magnitudes, R is made up of two resistances—that interior and that exterior of the element. The internal resistance, or resistance of the element, is again the sum of the several resistances due to the passage of the current from one plate to the liquid, to its passage through the liquid, and from its passage from the liquid to the other plate. We will call this resistance of the element r. The remaining component, the external resistance, is that due to the passage of the current through the interiors of the plates, the wire connecting them, and through whatever conductor may be otherwise inserted between them. Let this be ρ. Substituting these values for R in (I.

$$I = \frac{E}{r+\rho} \quad . \quad . \quad . \quad . \quad \text{(II.}$$

"The truth of this equation may be proved experimentally as follows:

"Evidence of the direct proportion of the intensity to the electro-motive force is obtained by comparing the known function of the deflections of a magnetic needle of a galvanometer, due to a current in a circuit, in which r and ρ, the circuit resistances, remain constant, while the numbers of pairs are changed. The resistance r of a pair of plates of equal surface at the same distance diminishes as their surface is increased, and *vice versâ;* but the resistance of more pairs joined up in series increases proportionally to the number. Therefore we take a single pair of plates of known surface, and connect them in the circuit of a galvanometer, and of a length of wire, determined by a rheocord or other adjustible resistance, and note the deflection ϕ°. Then we double the electro-motive force E by inserting in the place of these two pairs of plates of each, double the surface of the former, by which the resistance r remains unchanged. The wire ρ remains also the same; but we have another deflection, ϕ_1. For the intensity I with the single pair we have the expression—

$$1) \quad . \quad . \quad I = F(\phi^\circ) = \frac{E}{\rho + r}$$

and with the second reading by the two pairs—

$$2) \quad . \quad . \quad I_1 = F(\phi_1^\circ) = \frac{2E}{\rho + r}$$

F being the function, sine, tangent, or whatever it may be, which connects degrees of arc with those of force. From these two equations it follows, and will also be found, that

$$F(\phi_1^\circ) = 2\,F(\phi^\circ)$$
$$I = 2\,I$$

"The same method of experimental proof may be extended to n elements, connected in series, by increasing the surfaces n times. The remaining relation expressed by Ohm's law, that of current and resistance, is proved experimentally by obtaining a deflection ϕ_1, with a certain inserted resistance ρ, and electromotive force E, and then doubling the length of the wire ρ, diminishing the size of the plates to half, and doubling their distance from each other, by which the total resistance of the circuit is doubled, while the electro-motive force remains the same, and the needle is deflected a smaller angle ϕ_1°. Expressed algebraically, the first observation gives

$$1) \quad . \quad . \quad I = F(\phi^\circ) = \frac{E}{r + \rho}$$

and the second

$$2) \quad . \quad . \quad I_1 = F\,(\phi_1^\circ) = \frac{E}{2\rho + 2\,r}$$

from which it follows that

$$F\,(\phi^\circ) = 2\,F\,(\phi_1^\circ)$$
$$I = 2\,I_1$$

which will be verified by reducing the reflections to degrees of force. A law, upon which the truth of these results depends, has yet to be proved. It is that the resistance is reciprocal, and the intensity thereof directly proportional to the surface of the plate and to the section of the conductor. If the plates be first immersed a known fraction of their surface in the solution, and afterwards other fractions and completely, and at the same time the sectional area of the conductor be similarly increased, by taking thicker wire or two or more wires of the same length and diameter parallel to each other, the intensity, as indicated by the functions of the galvanometer, will be found to increase, other things being equal, as the section of the conductor and surface of the exciting plates increase. The application of Ohm's law in the solution of different problems which the electrician finds it necessary to answer is very extended; it forms, in fact, the basis upon which all exact inquiry in electrical science is built up. We will see now, as an instance, what it affords us when we combine elements together in different ways.

"When the poles of a pair of plates are joined together, the intensity, I, of the current passing in every section of the current is $I = \frac{E}{r+\rho}$. There are two principal ways in which a number of galvanic pairs may be connected together. 1st. They may be connected in series for intensity, so as to add their electro-motive forces and resistances together; and (2nd) they may be connected parallel to each other for quantity, as it is called, so that the electro-motive force of the combination remains the same; but the surfaces of the plates are increased, and hence the resistance in the same measure diminished. First, let n elements be connected thus· the negative pole of the first element is joined to the positive pole of the second, the negative pole of the second to the positive pole of the third, and so on, up to the nth element. We have then what is vulgarly called an 'intensity battery,' and the intensity of each individual element of the series. if they are of the same size and kind, will be

$$I = \frac{E}{\rho + r + (n-1)\,r} = \frac{E}{\rho + n\,r} \quad . \quad . \quad . \quad (III.$$

and that of the whole battery

$$I_n = n\,\frac{E}{\rho + n\,r} \quad . \quad . \quad . \quad . \quad . \quad . \quad (IV.$$

When the resistance, $n\,r$, of the battery is so small in comparison with ρ, that we can, without appreciable error, neglect it, the intensity of the whole battery becomes

$$I_n = \frac{n\,E}{\rho} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (V.$$

That is to say, that when the resistance of the battery is very small in comparison with the resistance of the circuit exterior to the battery, the strength

of the current is increased in direct proportion to the number of elements added to it. Dividing both numerator and denominator of the above fraction (IV.) by the number of elements, n, we get

$$\frac{E}{n}+r$$

which becomes, if we set $\rho=0$,

$$I_n=\frac{E}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (VI.$$

affording us light upon another relation of the galvanic current, viz., that when the resistance exterior to the battery is so small that it may be neglected, the current of a number of elements will do more work than that of a single pair.

"The first of these laws applies to a battery used for working a long line of telegraph, whose resistance with the coils of the apparatus is very great in comparison to that of the element, and where it is evident that a large battery is necessary.

"The second law applies to a local circuit, where the resistance of the circuit is small, and a few elements do as well as a great number."

THE RHEOSTAT OF WHEATSTONE.

The Rheostat, or Current Regulator.—We print from the memoirs of Sir Charles Wheatstone, in the Transactions of the Royal Society, "An account of several new instruments and processes for determining the Constants of a Voltaic Circle." This most distinguished philosopher says:

"The instruments and processes I am about to describe being all founded on the principles established by Ohm in his theory of the voltaic circuit, and this beautiful and comprehensive theory being not yet generally understood and admitted, even by many persons engaged in original research, I could scarcely hope to make my descriptions and explanations understood without prefacing them with a short account of the principal results which have been deduced from it.

"It will soon be perceived how the clear ideas of electro-motive forces and resistances, substituted for the vague notions of intensity and quantity, which have been so long prevalent, enable us to give satisfactory explanations of most important phenomena, the laws of which have hitherto been involved in obscurity and doubt. Viewing the laws of the electric circuit from the point at which the labours of Ohm has placed us, there is scarcely any branch of experimental science in which so many and such various phenomena are expressed by formulæ of such simplicity and generality. In most of the physical sciences, the facts of observation and experiment have kept pace with theoretical generalization. In this science alone they had gone on accumulating in prolific abundance without any successful attempt having been made to reduce them to mathematical expression. But this is now happily effected; and what has hitherto been mere matter of speculative conjecture is removed into the domain of positive philosophy.

"By electro-motive force is meant the cause which, in a closed circuit, originates an electric current, or, in an unclosed one, gives rise to an electroscopic tension. By resistance, is signified the obstacle opposed to the passage

of the electric current by the bodies through which it has to pass; it is the inverse of what is usually called their conducting power. When the activity of any portion of the circuit is increased or diminished, either by a change in the electro-motive force or in the resistance of that portion, the activity of all the other parts of the circuit increases or decreases in a corresponding degree; so that the same quantity of electricity always passes in the same instant of time through every transverse section of the circuit. The force of the current is directly proportional to the sum of the electro-motive forces which are active in the circuit, and inversely proportional to the total resistance of all its parts, or, in other words, the force of the current is equal to the sum of the electro-motive forces divided by the sum of the resistances.

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"It is seldom that any real advance is made in a scientific theory without a corresponding change in its terminology being required. Now that it is proved, beyond doubt, that the various sources of continued electric action differ from each other only in the amount of their electro-motive forces, modified by the resistances of the circuit of which they form a part, it becomes of importance, in order to give precision to our statements, and to avoid circumlocutions otherwise inevitable, to adopt general terms to express the source of a current, without reference to the peculiar mode of its production. I shall, therefore, employ the word 'rheometer' to denote any apparatus which originates an electric current, whether it be a voltaic current or a voltaic battery, a thermo-electric battery, or any other source whatever of an electric current. When speaking of a single element, I shall term it a rheomotive element; and what is usually called a voltaic or thermo-electric pile or battery I shall term a rheomotive series. I shall still use the ordinary expressions when I have to refer to the specific sources of the productions of electric currents; but when I employ the general terms, they must be understood to apply to all these sources indifferently. The want of a general term to designate an instrument to measure the force of an electric current, without reference to its particular construction, has been long felt. I shall use the word rheometer for this purpose, continuing occasionally to employ galvanometer, voltometer, &c., to distinguish the particular instruments to which these names have been applied—though, perhaps, the terms magnetic, chemical, calorific, &c., rheometer would be more appropriate.

"This may be the proper place to explain a few other terms, which I have frequent occasion to use, though not in the course of the present communication. By rheotome is meant an instrument which periodically interrupts a current; and by rheotrope, an instrument which alternately inverts it. A rheoscope is an instrument for ascertaining merely the existence of an electric current. The word rheostat will be explained hereafter.

"I have not introduced these terms (which will be found greatly convenient, and will enable us to state general propositions much more clearly) without good authority. The word 'rheophore' was employed by Ampère to designate the connecting wire of a voltaic apparatus as being the carrier or transmitter of the current; and the word 'rheometer,' first proposed by Peclet as a synonym for galvanometer, has been generally adopted by the French writers on physics.

"The method of obtaining the constants of a rheophoric circuit, adopted by Fechner, Lenz, Pouillet, &c., in their experimental verifications of Ohm's theory, is essentially the following: The resistance of a circuit is determined

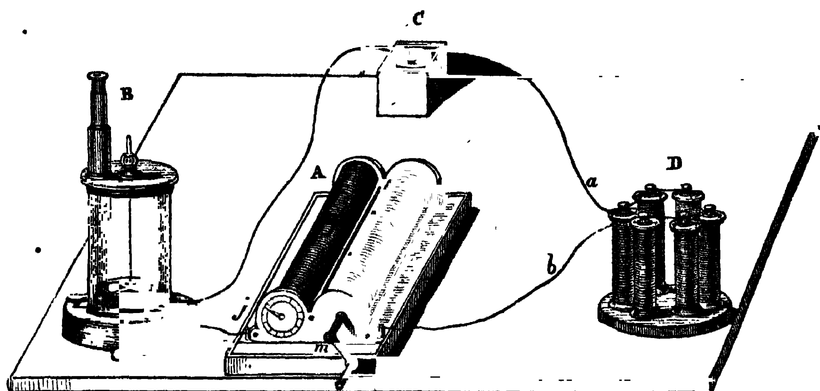


FIG. 301.

by observing the force of the current first, without any extra-interposed resistance in the circuit; and afterwards, when a known resistance is added. The principle of this method is extremely simple; but the difficulty of determining immediately the force of a current by means of a galvanometer is an obstacle to its general employment. Fechner measured the force of the current by the number of oscillations of the needle when placed at right angles to the coils—a very tedious operation; and others have employed the deviation of the needle, the corresponding degrees of force having been previously determined by some peculiar process, or inferred from some rule depending on the particular construction of the instrument. Another impediment to the use of the galvanometer, to measure the force of a current, arises from the changes in the magnetic intensity of the needle, which frequently occur, especially when it has been acted upon by too strong a current.

"The principle of my method is that of employing variable, instead of constant, resistances, bringing thereby the currents in the circuits compared to equality, and inferring from the amount of the resistance measured out between two deviations of the needle the electro-motive forces and resistances of the circuit according to the particular conditions of the experiment. This method requires no knowledge of the forces corresponding to different deviations of the needle. To apply this principle, it is requisite to have a means of varying the interposed resistance, so that it may be gradually changed within any required limits. I have contrived two instruments for effecting this purpose—one intended for circuits in which the resistance is considerable, the other for circuits where the resistance is small.

"The first instrument is represented in Fig. 301 A: *g* is a cylinder of wood, and *h* is a cylinder of brass, both of the same diameter, and having their axes parallel to each other; on the wood cylinder a spiral groove is cut, and at one of the extremities a brass ring is fixed, to which is attached one of the ends of a long wire of very small diameter, which, when coiled round the wood cylinder, fills the entire groove, and is fixed to its other end—to the remote extremity of the brass cylinder. Two springs, *j* and *k*, pressing one against the brass ring on the wood cylinder and the other against the extremity of

the brass cylinder *h*, are connected with two binding screws for the purpose of receiving the wires of the circuit. The movable handle *m* is for turning the cylinders on their axes. When it is placed on the cylinder *h*, and is turned to the right, the wire is uncoiled from the wood cylinder and coiled on the brass cylinder; but when it is applied to the cylinder *g*, and is turned to the left, the reverse is effected. The coils on the wood cylinder being insulated and kept separate from each other by the groove, the current passes through the entire length of wire coiled upon that cylinder; but, the coils in the brass cylinder not being insulated, the current passes immediately from the point of the wire which is in contact with the cylinder to the spring *k*; the effective part of the length of the wire is, therefore, the variable portion that is on the wood cylinder.

"In the instrument I usually employ, the cylinders are 6 in. in length and 1½ in. in diameter; the threads of the screw are forty to the inch; and the wire is of brass, 1-100th of an inch in diameter. I employ a very thin wire and a badly conducting metal in order that I may introduce a greater resistance into the circuit. A scale is placed to measure the number of coils unwound; and the fractions of a coil are determined by an index which is fixed to the axis of one of the cylinders, and points to the divisions of a graduated circle.

"As the principal use of this instrument is to adjust or regulate the circuit, so that any constant degree of force may be obtained, I have called it a rheostat. Fig. 301 shows the arrangement of the circuit when prepared for an experiment; B is a delicate galvanometer with an astatic needle, furnished with a microscope for reading off the divisions of the circle, which greatly facilitates the observations; C is the rheomotor.

"The rheostat which I employ for circuits in which the resistance is comparatively small is represented at Fig. 302. *a* is a cylinder of well-seasoned wood, on the surface of which a spiral groove is cut. A thick copper wire is wound round the cylinder, occupying the groove, forming, as it were, the thread of the screw. Immediately above the cylinder, and parallel with its axis, is a triangular metal bar, *b*, carrying a rider or slide, *c*; to this rider a spring, *d*, is fixed, which constantly presses against the spiral wire, yielding to any slight inequality. One end of the spiral wire is attached to a brass ring, *e*, against which a spring, *f*, presses, which is connected by means of a binding-screw to one end of the circuit: the other end of the circuit is held by the binding-screw which is in relation with the triangular metal bar. On turning the handle *h*, the cylinder is caused to move on its axis in either direction; and the rider *c*, guided by the wire, moves along the bar, advancing or receding according as the cylinder is moved right or left. The rider coming in contact with a different point of the spiral wire, a different resistance is introduced into the circuit, consisting of that portion of the wire only which is included between the rider and the end of the wire connected with the spring *f*.

"The cylinder of the instrument I have constructed is 10½ in. in length and 3¼ in. in diameter: the wire is of copper, 1-16th of an inch thick; and it makes 108 coils round the cylinder. The dimension of the instrument, and the thickness, length, and material of the wire, may be varied according to the limits of the variable resistance required to be introduced into the circuit, and the degree of accuracy with which those changes are required to be measured.

"Fig. 302 represents the arrangement of a thermo-electric circuit in which

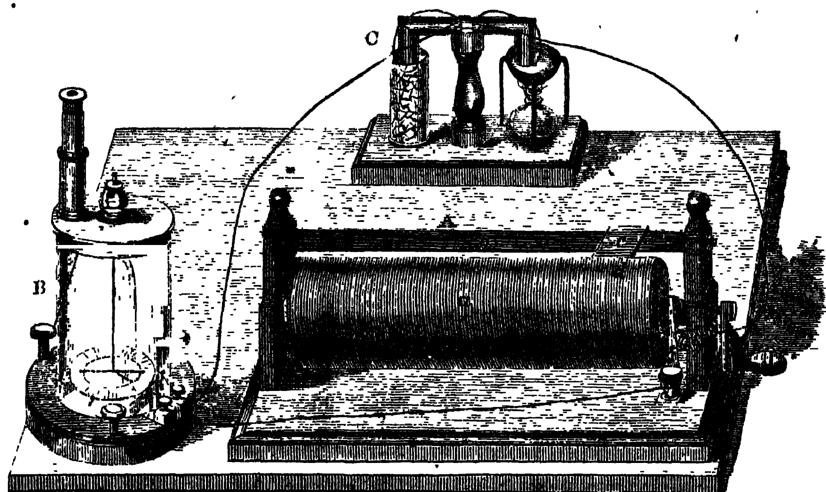


FIG. 302.

this instrument is interposed. C is the thermo-electric element; B, the galvanometer, which in this case must not have numerous coils of fine wire, as in the preceding arrangement—for this would introduce too great a resistance in the circuit--but must consist of a single thick plate or wire, making a single convolution; or, which I think is preferable, the method of diverting a portion of the current from the wire of a delicate galvanometer described may be adopted. Any rheometer in which the resistance is small may be employed in conjunction with this form of the rheostat, instead of a thermo-electro element described. The rheostat, especially under the form last described, may be usefully employed as a regulator of a voltaic current, in order to maintain for any required length of time precisely the same degree of force, or to change it in any desired proportion. Interposed in the circuit of an electro-magnetic engine, however, the rheometer may vary in its energy; the same velocity may be constantly restored by turning the cylinder of the regulator to the left or to the right, according as the velocity increases or decreases; or any different velocity, within given limits, may be obtained by adjusting the rheostat accordingly.

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"It is of the highest importance to have a correct standard of resistance, and one that can easily be reproduced for the purpose of comparison. A copper wire of a given length and diameter might be employed; but, as very small differences of diameter are attended with considerable differences in the resistances of wires, it is more convenient to assume for the unit of resistance a wire of a given length and weight, which allows small differences to be very accurately determined.

"It is frequently required to measure resistances much greater than can be effected by means of the rheostat, though the reduced length of its wire is

considerable. I may wish to know, for instance, the resistance of the wire of the electro-magnets of my telegraphic apparatus, which is sometimes many hundred yards in length, or that afforded by an extensive telegraphic line, or the resistance of a certain extent of an imperfectly conducting liquid. In all these cases, and a variety of others, I employ another instrument, which enables me to interpose in the circuit resistances to any amount, and yet to obtain by the compound use of the rheostat, which serves, in its fine adjustment, any required degree of accuracy. This instrument is represented at Fig. 301. It consists of six coils of fine silk-covered copper wire, about the 1-200th part of an inch in diameter: two of these coils are 50 ft. in length; the others are respectively 100, 200, 400, and 800 ft. in length. The two ends of each coil are attached to short thick wires, fixed to the upper faces of the cylinders, which serve to combine all the coils in one continued length. The two wires, *a*, *b*, form the extremities of the coils by which they are united to the circuit. On the upper face of each cylinder is a double brass spring, movable round a centre, so that its ends may rest at pleasure either on the ends of the thick connecting wires, or may be removed from them and rest only on the wood. In the latter condition the current of the circuit must pass through the coil; but in the former position the current passes through the spring, and removes the resistance of the coil from the circuit. When all the springs rest on the wires, the resistance of the whole series of coils is removed; but, by turning the springs so as to introduce different coils into the current, any multiple of 50 feet up to 1600 may be brought into it.

"As the measurement of these long lengths of wire cannot be accurately depended upon, it is advisable to ascertain the number of units of resistance in each coil, which, with the aid of the rheostat, may be easily effected. I find the resistance of the entire 1,600 feet to be equivalent to 218,880 units of resistance, or feet of the standard wire. I occasionally employ an auxiliary series of coils, combined in the same way as the preceding, consisting of six coils of the same wire, each 500 yards in length. The reduced length of this series is above 233 miles of the standard wire. By combining it with the preceding, I am able to measure resistances equal to 274½ miles.

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"The rheostat affords a most ready means of ascertaining the sum of the electro-motive forces active in a voltaic circuit, without requiring for this purpose the aid of a rheometer graduated to indicate proportional forces, or having recourse to the tedious process of counting the oscillations of a needle, employed by Fechner in his investigations. To save time and trouble in this operation will be of great importance to the future progress of electro-chemistry, on account of the great number of experiments of this kind which yet remain to be made, and also from the fluctuations in the electro-motive forces of many circuits, from chemical and other actions, which render observations requiring considerable time valueless.

"The principle of my process is as follows:—In two circuits producing equal rheometric effects, the sum of the electro-motive forces divided by the resistances is a constant quantity, *i.e.*, $\frac{E}{R} = \frac{n\,E}{n\,R}$; if E and R be proportionately increased or diminished, F will obviously remain unchanged. Knowing, therefore, the proportion of the resistances in two circuits producing the same effect, we are able immediately to infer that of the electro-motive forces.

"But as it is difficult in many cases to determine the total resistance, consisting of the partial resistance of the rheometer itself, the galvanometer, the rheostat, &c., I have recourse to the following simple process:—Increasing the resistance of the first circuit by a known quantity, r, the expression becomes $\frac{E}{R+r}$. In order that the effect in the second circuit shall be rendered equal to this, it is evident that the added resistance must be multiplied by the same factor as that by which the electro-motive forces and original resistances are multiplied; for $\frac{E}{R\,r} = \frac{n\,E}{n\,R + n\,r}$. The relations of the lengths of the added resistances r and $n\,r$, which are known, immediately give those of the electro-motive forces. Experimentally, I proceed thus:—I interpose the rheostat and the galvanometer in the circuit, and then add by means of the former, assisted if necessary by the resistance coils, a sufficient resistance to bring the needle exactly 45°. I then ascertain the length of wire uncoiled from the brass cylinder of the regulator necessary to reduce the deviation of the needle to 40°. The number of turns is the measure of the electro-motive force, the number corresponding to that of a standard element having been previously determined."

The description of Sir Charles Wheatstone's differential-resistance measurer will be found in the article on the Telegraph, under the name of "Wheatstone's British Association Bridge."

THE CALORIFIC EFFECTS OF THE VOLTAIC CURRENT.

When the poles of the battery, or rather the terminal wires, are connected with the arms of the universal discharger, to which crayon-holders, containing hard gas-retort carbon, have been attached, no effect is observed until the carbons are brought in contact, because the intensity of the voltaic current is

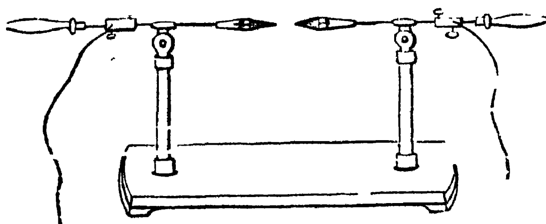


FIG. 303.—*The Charcoal Points.*

not sufficient to polarize the intervening air and cause a disruptive discharge; but, once brought in contact, a brilliant spark or intense light is perceptible; and then the carbons may be more or less separated without interrupting the current; and, with very powerful batteries, the distance between the two carbons may be increased to several inches.

By throwing a picture of the charcoal poles on the disc, it is seen that a luminous arc extends between the two poles, and there is a constant transference of heated particles going on between the two carbons. It is this passage

of divided carbon which serves as a conductor to the current, and preserves its continuity.

De la Rue states that "The length of the luminous arc consequently bears a close relation to the facility with which the *material* of the poles admits of *division*."

Scientific men have always agreed that the transference of particles took place in the same direction as the current, viz., from the positive element to the negative; and the explanation is made clearer by the discovery of Neeff, that the positive is more strongly heated than the negative pole.

Van Breda has shown that incandescent and fused particles are not only propelled from both poles towards one another, but in every direction.

Maas, of Namur, affirms that the transference does not always take place from the positive to the negative pole, but is determined by the density of the charcoal. He states that he succeeded in reversing the direction of the particles by connecting a very hard, fine-grained bit of carbon with the positive, and a coarse, soft piece of charcoal with the negative; and he then found that the incandescent particles moved from the negative to the positive pole.

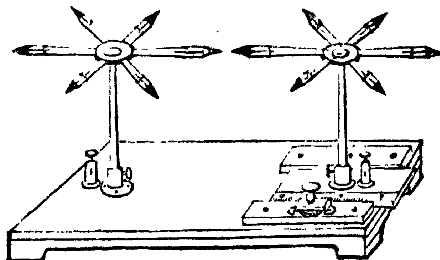


FIG. 304.

The negative cylinder, when examined, appeared slightly excavated; the positive one, slightly obtuse. Amidst this conflicting evidence, the writer states from experience that the wasting of the charcoal points is always unequal, and, provided they are of the same quality, the transference takes place regularly from the positive towards the negative. By arranging a number of crayon-holders, containing various metals, such as zinc, copper, lead (Fig. 304), according to the method proposed by Mr. De la Rue, a number of beautiful colours may be obtained by the intense heating and partial combustion of the metals, copper throwing out a green light, zinc a bluish white, with the formation of a large quantity of smoke—oxide of zinc.

If the charcoal points are brought together in a void space, or vacuum, the light is very peculiar: it appears softer, though still very brilliant, and presents a marked difference to the same light observed in air; the carbons appear to last much longer, and the writer has often thought that when the electric light is required to be very continuous, as in the Duboscq lantern, it would always be better, if possible, to produce the light in small glass chambers from which the air had been removed.

It has been seen that the resistance of platinum wire to the passage of the electric current is at least nine and a half times greater than that of silver.

When a wire resists the passage of the current, viz., motion, heat is the

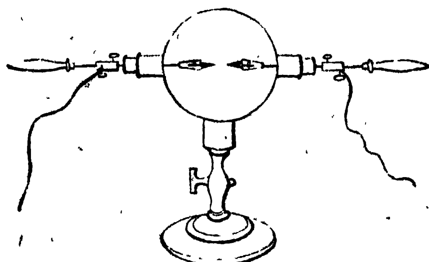


FIG. 305.—*Electric Light in vacuo.*

product, which may be so increased by the reduction of the thickness of the metal, that it becomes intensely hot.

A platinum wire of moderate thickness stretched between two upright pillars, of course metallic, becomes ignited throughout its entire length, if connected with a battery of sufficient power. The writer has had 18 feet of wire incandescent whilst using very powerful Grove's batteries. For experiments on the small scale, it is well to protect the platinum from the cooling action of currents of air, and by this means a much greater length of platinum

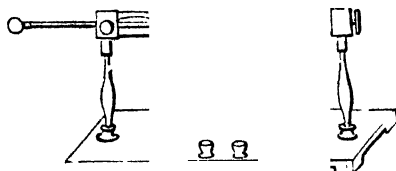


FIG. 306.—*Glass Tube containing a Platinum Wire,*

Attached to one end and connected with a sliding brass rod, which being drawn out lengthens or shortens the platinum wire.

wire can be ignited. The light emitted is peculiar, and the wire appears four or five times thicker than it really is, by irradiation. In a vacuum, a wire of platinum may be ignited which would remain cold and dark in the air. A platinum wire which is thoroughly ignited in air remains perfectly cool if surrounded with hydrogen gas. This fact is easily shown by using two bell-jars of the same size, one full of air and the other filled, by displacement, with hydrogen from an india-rubber bag. As the jars are alternately placed over the platinum wire, the latter becomes incandescent in the air, but cool in the hydrogen (Fig. 307). This fact was discovered by Professor Grove, but is not yet clearly explained. Magnus ascribes it to conduction; and theoretically this idea seems more consistent with the statement that hydrogen is really a metal. Tyndall ascribes it to the convective mobility of the gas; its particles are supposed to be more quickly set in motion than air, and hence carry off more heat.

The dynamical effect of electricity, and its power of producing motion, is well shown in the movements of the magnetic needle belonging to the galva-

nometer, and will be more fully described in the article upon Electro-Magnetism; and having now discussed the various effects producible from the voltaic current, viz., chemical, calorific, magnetic, and dynamical, we may

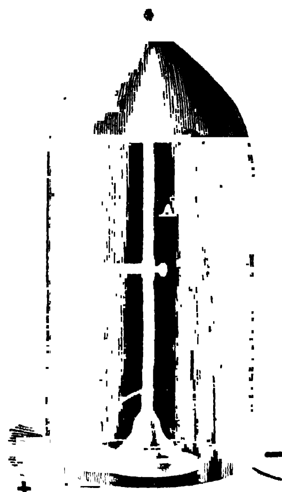


FIG. 307.
A, glass rod, insulating the top pole, B, from C, between which the coil of platinum, P, is placed.

conclude this chapter with the description of a few practical applications of the principles already described.

First, the use for surgical purposes, by Mr. Sylvan De Wilde, C.E., of the Electrical Probe and Forceps.

Blood, bone, and animal matter generally are practically non-conductors of electricity of low tension.

Soft iron, around which an electric current is made to circulate, becomes instantly magnetic. The magnetism ceases the instant the current is broken —constituting what is called an electro-magnet.

Advantage is taken of these properties to detect the existence and assist in the extraction of bullets from wounds.

The apparatus consists principally of four parts: 1, the battery; 2, the alarum; 3, the probe; and 4, the forceps, contained, with their accessories, in a box 11 in. × 3¼ in. × 2½ in., and is complete in itself, requiring no external supplies for about three years.

The Battery.—Electricity is developed in a vulcanite cell (on the left of the bell) by zinc and carbon, in a solution of sulphate of mercury. The pieces of zinc and carbon drop into slots in the interior ends of the cell, where they impinge upon platinum springs, which, being riveted to conductors on the exterior of the cell, form positive and negative poles.

The zinc and carbon are interchangeable, it being immaterial as to which way the current travels through the apparatus.

The poles of the battery come into contact with the conductors of the

alarum at the top of the partition on the left of the bell, and it is necessary to see that the metallic surfaces are clean, as a thin film of dirt or oxide will prevent the passage of the current.

The Alarum.—This consists of brass strips or conductors (mounted on an insulating bed of vulcanite) which proceed from the poles of the battery to the *binding-screws* or *terminals*, which stand on the partition to the right of the bell. One of these conductors, on its road, passes in the form of silk-covered wire many times round pieces of soft iron, forming together an electro-magnet. It is on the immediate right of the bell. The instrument so far may be tested by making communication between the two terminals or binding-screws with a knife-blade or any metallic conductor. This completes the circuit: the current passes, the iron is magnetised, the keeper (to which is attached the hammer) attracted, and a stroke given on the bell. We may thus know that the battery is in action, and all metallic contacts clean and of sufficient pressure, before attaching the wires of the probe and forceps to the terminals.

The alarum is covered with glass, to keep out dirt, which is considered a greater evil than the partial muffling of the sound. Should a violent jerk affect the adjustment of the hammer upon the bell, the glass can be removed by taking the screws out of the beading. A piece of steel which will serve this purpose will be found in the receptacle on the left of the battery. The bell must be turned upon its axis (which is excentric) until a position is found which gives a clear ring.

The *Probe* consists of two pointed steel wires firmly fixed in an ivory handle, and projecting about 4 in. from it. These wires are insulated from each other by a strip of vulcanite lying between them. Between the points and the handle, the wires have a slender vulcanite tube passed over them, which is screwed into a short length of German silver tube, upon which is mounted a small shield. The tubes, thus screwed together, are free to slide to and fro about a quarter of an inch, being pushed forward by pressure of the second finger upon the shield, and thrown back by a spiral spring which obtains purchase upon two screws inserted in the ivory handle through slots in the German silver tube.

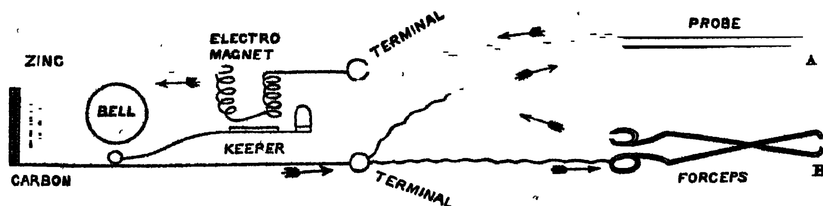


FIG. 308.

The *Forceps* consists of two tempered steel limbs, having curved and bow handles like scissors. One of these limbs has riveted upon it a slip of ivory, which, combined with ivory bushing of the pivot and the small piece of ivory between the bows, completely insulates it from the other, in all positions.

To the bows are screwed and soldered very pliable plated wires, 2 ft. long, covered with silk, which are coupled and soldered to similar wires proceeding from the two steel wires of the probe.

It will be seen from the above sketch that each instrument has the electrical current "laid on," but broken at A and B (the points of the probe and of the forceps). Let each instrument be tested immediately before use by touching and seizing a bullet, which will supply a bridge for the current to pass at A and B, and instantly cause the bell to ring. It is needless to say that the instruments cannot be used quite simultaneously.

The box in the right-hand compartment contains about forty charges of the battery, each charge lasting several weeks. Shaking the battery-cell about will often revive an apparently dead solution. It ends by gradually getting too feeble to attract the keeper. It should then be thrown away, the cell washed out, and fresh charged when required.

Method of using.—The probe being handled as a pen, the shield is pushed forward by the second finger; this has the effect of covering the points of the wires with the vulcanite tube. The instrument is now inserted, and the wound explored until the supposed bullet is felt. The tube is then allowed to retreat, by the withdrawal of the second finger, and the substance is examined with the points. As it is necessary that both points should touch the metal at once, it will follow that, as the probings are carried on, quarter and half revolutions of the probe on its axis should be made, by rolling it between the fingers, as we might otherwise touch with one point only, and obtain no signal, as for instance on the back edge of a bullet at A.

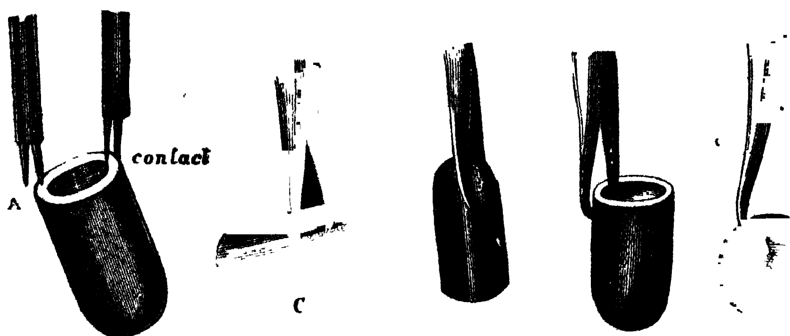


FIG. 309.

If the points become entangled in fibre, &c., they can always be released by sliding forward the tube for a moment. The advantage of points is their ability to obtain good contact through pus or fibre which may overlie the bullet.

The lodgment being ascertained, the forceps are brought into use; and these equally give a ring upon the bell when the bullet is seized, the falling back of the bell-hammer showing if contact is lost. The curved points will seize the bullet in any position, generally allowing it to revolve to that of least resistance. As for instance, should seizure be made at right angles to the bullet, it would revolve between the points, as shown by the sketch at C and D.

In many cases the forceps could be at once used, without the intervention of the probe.

Should the plaited wires, by repeated twisting, become broken, they may

be resoldered by any tinman or the regimental smith, or, in emergency, tied on or fastened in any way so that fair metallic contact is made.

The probe was invented by Mr. De Wilde to solve the difficulty presented in the case of General Garibaldi. It is made by Mr. Apps, and was submitted to the Director-General of the Army Medical Department in December, 1866, and, shortly after, approved in a report by Professor Longmore, of Netley Hospital, and by the Directors-General of the Navy and of the Indian Board.

THE ELECTRIC TORPEDO.

Among the many important applications of electricity the electric torpedo occupies a very prominent position, as a means of defence against the approach of an enemy both by land and by sea.

By sea this defence against attack is carried out by sunken torpedoes or mines, containing charges of gun-cotton or gunpowder proportionate to the depth of water, and which are planted in the harbour or channels to be protected, in such positions that the enemy's ships in their approach must pass over them, and, upon the ignition of the torpedo, be destroyed by its explosive force.

On land, the torpedo assumes the form of a hidden mine, any number of which may be grouped around the city or place to be protected from the approach of the enemy. These mines are large pits in the form of inverted truncated cones, into the apex of which the torpedo is placed, the rest being filled with one or two hundred tons of paving-stones and broken granite, and the mine concealed from observation; but, when it is fired, it will deal death and destruction to all around.

The ignition of these torpedoes by land and by sea is effected by means of the electric spark, and, by the arrangement of Mr. Nathaniel J. Holmes, is entirely under the will and control of the operator, and may be employed with the greatest safety, while at the same time it is certainly one of the most deadly and destructive engines of warfare which the mind of man has devised.

Of the horrors of the torpedo the American struggle between North and South affords example, and the following narrative of the blowing up of a large five-gun vessel, with a crew of a hundred and twenty men, by means of one of these torpedoes, will suffice.

The explosion took place on a clear afternoon, and was witnessed by many persons. The boilers, engines, and smoke-stack went up 20 or 30 feet, the boilers bursting at the same time, and the hull of the vessel was reduced to fragments, while the bodies of the crew were projected high in the air, and in many cases their garments were, by the force of the explosion, rent from their bodies, and heads, arms, and limbs were scattered in all directions. Not one of that crew came down alive. This vessel was destroyed in the James River, and stopped the advance of the Federal fleet for a week. Again, on the 15th of December, 1864, while in Mobile Bay, the gun-boat "Narcissus" was blown up by a torpedo, and crew and vessel annihilated in a moment. Admiral Farragut's ship, the "Richmond," which happened to be within 50 feet of the torpedo, was also damaged, and several of the men on board frightfully scalded and mutilated. The Americans may with justice remark, these torpedoes are *infernal things*.

The torpedo was first introduced into naval warfare by the Russians during the advance of the British fleet into the Baltic, at the time of the Crimean war, in 1854.

These torpedoes, constructed by Professor Jacobi, were small iron tanks, filled with gunpowder and a charge of chlorate of potash and sugar, and fired by percussion, that is, coming into contact, as they floated down the stream, with the hull of any vessel they chanced to meet. An iron rod, projecting, would strike the ship, and by the force of the shock be driven back and break a vessel containing sulphuric acid within the charge, and so explode the mine.

The nature of the construction and ignition of these torpedoes rendered them as likely to be injurious to friend as well as foe, and in time the percussion arrangement corroded, and, when required for service, they were often found useless; and no improved method of construction being then known, the torpedo was abandoned until the year 1860, when the Austrian government took up the subject in connection with the defence of Venice, by the closing of the harbour and three important channels by electric torpedoes.

To Baron Ebner is due the merit of these investigations into the proper construction and discharge of torpedoes for naval defences, and he also carried out a series of experiments regarding the destructive effects of certain charges of gun-cotton and gunpowder under ascertained conditions, but which were interrupted, after the armistice, after the placing of five torpedoes. In these experiments nothing really practical was developed by which the torpedo could be introduced generally into naval and military tactics as an auxiliary to rifled guns and ironclads; and to Mr. N. J. Holmes and Commander Maury, the deep-sea hydrographer, belong the merit of reducing the whole practically into a system.

In the month of August, 1863, during the meeting of the British Association, at Newcastle-on-Tyne, Mr. Holmes carried out the novel idea of firing an 18-pounder cannon at Newcastle each day at 1 p.m., Greenwich time; the electric spark to discharge the gun being flashed through the wire from the Royal Observatory, Calton Hill, Edinburgh, a distance of 120 miles. By the able assistance of Professor Piazzi Smythe, the Astronomer Royal for Scotland, the necessary connections at the observatory with the clock were made; and each day the clock transmitted the current to the gun at Newcastle, which was discharged at 1 p.m., Greenwich mean time, to the gratification of the Association. This time-gun has since been permanently established, and is daily fired, enabling those at Newcastle, when they hear the report of the discharge of the gun, to set their watches and clocks according to correct Greenwich time. The means used for this experiment were, first, the spark developed from Sir C. Wheatstone's magneto-exploder; and, secondly, the excellent chemical fuse of Professor Abel, of the Royal Laboratory, Woolwich, and which, being inserted into the touch-hole, in its ignition fired the gun.

Commander Maury, who witnessed this time-gun experiment, was struck with the importance of the application for the ignition of torpedoes as a means of assisting the defences of the Confederate armies in the struggle then going forward. Commander Maury and Mr. Holmes commenced a series of experiments, and the result of their labours may be described as follows:—Before torpedoes can be safely relied upon for defence, the power of ascertaining if they are in perfect order is necessary, and that the enemy have not destroyed the submarine connections between the shore and the mine. This is accomplished by a peculiar arrangement of parts within the fuse, charge, and mine, whereby the testing spark shall pass harmlessly through the mine without exploding it, and telegraphing through the entire series of mines without risk

or danger. The importance of testing the wires by sending an intensity current from Sir Charles Wheatstone's magneto-electric telegraph through the torpedo is easily explained. According to the old plan, a large charge of gunpowder was placed under the water, and the two conducting wires connected with it brought to the shore; and on a vessel passing over it, directly the terminals were attached to the voltaic battery the explosion took place. If torpedoes arranged in this simple way were placed under the water, and the enemy became aware of their existence, they would soon go to work to destroy them, by sending out at night, so as to be favoured by darkness, small boats, with men provided with the proper tackle, such as ropes and grapnels. On dragging the wires to the surface of the water and simply cutting them, not one of the torpedoes could then be fired, while those who had charge of them would not be aware of the circumstance, and expect to be able to fire them at any moment; on the contrary, the enemy's ships would be able to pass harmlessly over the torpedoes. Mr. Holmes has made a great improvement, by placing a coil of fine platinum wire in the circuit near to the fuse, so that the intensity current from a magneto-exploder or telegraph will not ignite the charge when it is allowed to pass through it. The men having charge of these torpedoes stationed probably three or four miles away, and the wires being connected with the magneto-telegraph, they could easily send or receive messages by currents of electricity passing through the torpedoes from one instrument to the other, and would thus afford satisfactory evidence of all being in a proper condition to fire. On the other hand, if they found suddenly the telegraph refused to work, and it was not in their power to send a message, then they would very likely say, "Depend upon it, our enemies have been at work and cut the wires. It is useless to waste our time; we had better employ some other means of defence to repel their ships, if they attempt to enter our port."



FIG. 310.

a, The Polytechnic Torpedo, constructed by the writer; and, b, Mr. Holmes's Torpedo made of iron boiler-plate.

We will now imagine that the wires have been satisfactorily tested, and that the moment has arrived for igniting the torpedoes. It may, however, be naturally asked, if intensity electricity will not fire them, how can they be exploded? We must here recollect, there are two qualities of electricity—intensity and quantity. The former is used only for testing the wires; the latter, quantity or accumulated, is used by Mr. Holmes for igniting torpedoes constructed

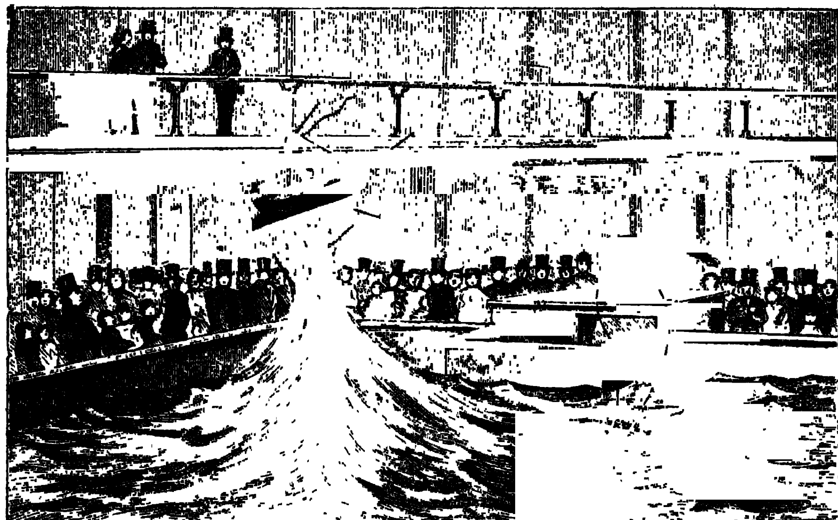


FIG. 311.

according to his plan. The Messrs. Elliott, of Charing Cross, have arranged a very convenient and portable frictional-plate electrical machine, with condenser or small Leyden jar combined, and, being made of ebonite, it is always in good working order. The wires being detached from the telegraph and connected with this machine, which becomes charged by about thirty revolutions, on pulling a little trigger at the side, the contact is made with the torpedo and the Leyden jar, and the quantity-spark is discharged in the centre of the fuse, and the explosion instantly takes place.

These torpedoes in practice are usually arranged in groups of three, and consist of vessels similar to steam-engine boilers, made of thick plates of iron riveted together, each one being charged with 500 lbs. of gunpowder. It can easily be imagined that one of these, placed 16 ft. under a ship and fired, would be quite sufficient to blow it into the air.

We give a drawing of the miniature torpedo experiment performed so frequently at the Royal Polytechnic, Mr. J. L. King, an old and much-respected pupil of the writer, now lecturer at the Institution, superintending the arrangements. A copper cylinder (Fig. 310, *a*), containing a few grains of gunpowder, and covered with bladder, is sunk in the centre of the great tank, to a depth of about 2 ft., and when the spark is passed it explodes, blowing a model ship high into the air, to the great delight of all small warriors of the rising generation.

THE ELECTRIC LAMP.

The young people who may read this book will, no doubt, be glad to hear that they can now experiment with the electric light at a very moderate cost, with a new and beautiful apparatus constructed by Mr. John Browning, of 111 Minories.

The apparatus, Fig. 312, is most simple and effective, and, with a small Grove battery and a moderate-sized lamp, an electric light may be procured at about the cost of two or three pounds. There is no clockwork; and the regulator is simply an electro-magnet which cannot very easily be put out of order. The writer can strongly recommend this apparatus to those who want a cheap and good lamp. Of course, when an electric lamp is required to be constantly used, and is subjected to much wear and tear, more substantial arrangements are required. as in Serrin's lamp.

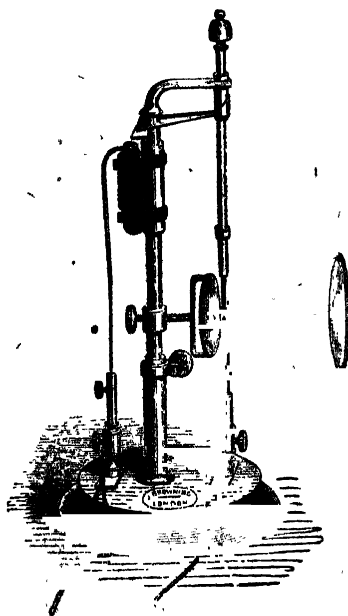


FIG. 312.—*Mr. Browning's new and cheap Electric Lamp.*

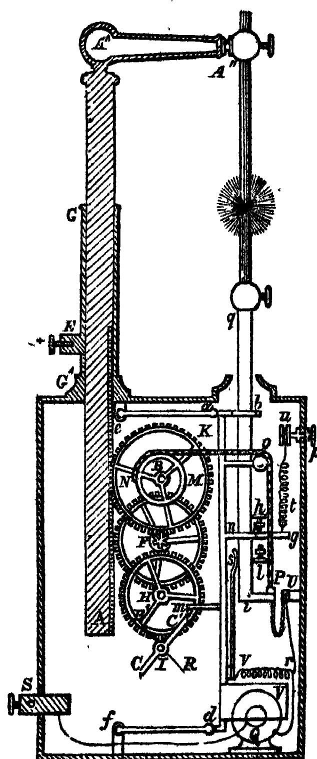


FIG. 313.—*Serrin's Automatic Regulator of the Electric Light.*

In the following description of Serrin's apparatus, Figs. 313 and 314 represent a vertical section and plan (at the height of the electro-magnet) of apparatus; it consists,

First, of a motor or driving power A, A′, A″, forming at the same time the motor and holder of the positive electrode, as a motor; it is furnished with a toothed rack, and acts by weight on the moving part of the clockwork. The tube G, G′, serves as a guide, which carries a binding-screw stud E, which serves to receive the wire from the positive pole of the battery.

Secondly, of a wheel train, composed of four movable parts, B, F, H, I, the first mover of a single piece forming at the same time a toothed wheel, K, and pulley, M. The diameter of these last are as two to one, so as to correspond

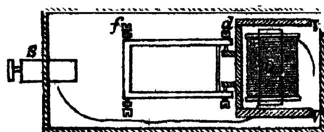


FIG. 314.

and be in proportion, as near as may be, to the different consumption of the positive and negative carbon points, and thus maintain the point of light stationary. To effect this, the wheel K, in turning under the action of the motor, A, A′, A″, allows the upper carbon point to descend, whilst the pulley M, by the same movement, winds up the chain N, O, P, and effecting at the same time the ascension of the lower carbon point. The toothed wheel K, in combination with the other movable parts, serves to regulate the approach of the carbon points by the aid of the flyer R, R′, which carries the last wheel. This carries besides a detent C, C′, which acts to prevent or permit the approach of the charcoal points.

Thirdly, of an electro-magnet, Q, wound round with an isolated conducting wire, communicating by one of its extremities to the binding-stud S, and by the other to small chains U, P.

Fourthly, the combination of parts, which I will term the oscillating arrangement, and which forms the particular feature of this improved regulator. *a*, *b*, *d*, oscillating support, properly so called, which is held by two arms of equal length, *a e*, *d f*, jointed, at *e f*, to the plates or case of the train; the joints, *e f* and *a d*, permit of a vertical to-and-fro movement of about half an inch, which movement is limited by a stop, *g*, oscillating between two screws, *h*, *l*.

The pulley O, which is mounted on the oscillating support and disposed to receive the chain N, O, P. I call this chain and pulley O the parts of ascension. The pawl or catch *m*, also fixed to the oscillating support, engages with or disengages from the teeth of the detent C, C′, according as it is to be raised or lowered: thus, when the stop *g* is in contact with the screw *h*, the gearing is free; if, on the contrary, it separates itself a fraction of an inch, the pawl *m* engages with and stops the train. *a*, *b*, *n*, *n′*, collars formed on the oscillating support; they are bushed with ivory, so as to isolate the lower carbon-holder, and serve at the same time to guide the latter in its raising movement.

The armature V, fixed to the oscillating support, is formed of a horizontal plate and two vertical plates of soft iron; the horizontal part covers the electro-magnet Q, and the other two are placed at opposite ends of the soft iron of the electro-magnet, but without touching it. This armature is disposed in such way that its central horizontal line is higher than the usual lines of the electro-magnet, thereby assisting the action of the magnet.

The appendix *i*, P, fixed to the base of the carbon-holder *i*, *q*, serves to join it with the chain N, O, P, electrically isolated at P.

The object of the small chains U, P, is for the passage of the electric cur-

rent, while at the same time they serve as a variable counterbalance by raising the extremity P, and thereby compensating for the loss of weight that the lower carbon incurs by being used in combustion. The fixed support U of the chains is electrically isolated. The friction surface *s*, *v*, is also isolated at *v*, the helix *v*, *r*, serving also to conduct a part of the electric current passing from the lower carbon to the wire of the bobbin.

The suspension spring has for its object to sustain the oscillating frame and effect of the weight; it can be lengthened or shortened at will by the aid of the button *p* and the pulley *u*.

Action of the Regulator.—The drawing represents the apparatus in action, and the carbon points about half used. The carbon points are placed in their supports A″, *q*, while the apparatus has no communication with a battery; the electro-magnet being inactive, the spring *t* should be lengthened in such way that the stop, *g*, presses lightly on the screw *h*, or in this case the detent C′, C″, being in gear with the hook *m*, is raised to its highest elevation. During this time the gearing is free, and the charcoal points approach and come in contact. By connecting the negative pole of the pile or battery to the binding stud, S, and the positive pole to the screw E, the electricity enters the apparatus by the latter, passes through the motor, carbon-holder, and the carbon itself by reason of the contact which exists between the two carbons; it will continue its course by the lower carbon, the support *i*, *q*, the small chains P, U, also the friction surface, *s*, *v*, and helix *v*, *r*, to the conductor wound on the electro-magnet, leaving by the binding-screw stud, S, to re-enter the battery, and so on. At the moment of connecting the second pole of the battery, the electro-magnet becomes active, and the armature, V, is attracted and drawn down, thus lowering the oscillating frame or system; the hook then catches the wheel train. By this action the train is stopped, and the upper carbon remains stationary, while the lower one being unable to rise, their separation is maintained, and the voltaic arc formed. The arc being formed, the carbon points are consumed by transfer and combustion; therefore the interval between them increases, while the attractive force of the bobbin becomes gradually weaker, and the oscillating system raises, its motion being complete when the screw-stud, *g*, touches the screw *h*, the train liberated at the same time and acts on the ascending parts, which thus effect the simultaneous approach of the two carbons; this approach is effected in relation to the unequal wear of the carbons so as to maintain the point of light stationary. After the approach of the carbons the electricity passes more easily, causing the armature to be attracted more strongly, and to overcome the resistance of the suspending spring so as to draw down the oscillating frame, when the hook gears with the train and prevents the carbons approaching until the wear again produces another approach, followed by another stop, and so on. Thus, by the alternate opening and closing of the circuit, the movements described can be reproduced and continued at pleasure, and so forming and determining the voltaic arc by its self-action. After the preceding, it will be seen that it is the oscillating system or frame which determines all the actions of the regulator, and separation and adjustment of the carbons. The seven principal pieces of which it is composed produce the different effects under the action of electro-magnetic apparatus in communication with the voltaic arc.

The recapitulation of the seven principal parts which compose the oscillating system or frame are the following:—First, the suspension spring *t*; secondly, the stop *g*; thirdly, the electro-magnet Q and V; fourthly, the carbon-

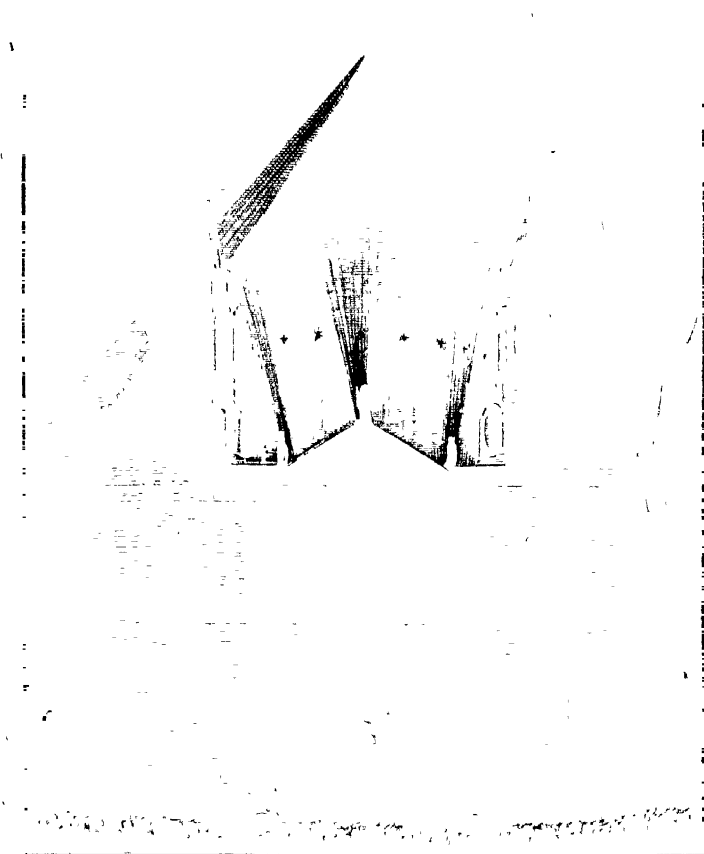


FIG. 315.—*Illumination of the Ball and Cross and Dome of St. Paul's by the Electric Light.*

holder *i*, *q*; fifthly, the ascending part O and N, O, P; sixthly, the hook of detent *m*; seventhly, the compensating chain U, P.

With a number of Serrin's lamps, Captain Bolton and the writer illuminated Trafalgar Square and St. Paul's Cathedral, on the occasion of the festivities connected with the nuptials of H.R.H. the Prince of Wales. The night was unfortunately too foggy to enable even the strongest lights to pierce the smoke-contaminated atmosphere of London, so that the imagination (unless, like the writer, the spectator was close to the soot-begrimed dome of St. Paul's) had to suppose what might have been the effect if the air had been free from the pea-soup mixture of aqueous vapour and smoke.



FIG. 316.—*The Shepherd discovering the Magnetic Stone on Mount Ida with the Iron of his Crook.*

MAGNETISM.

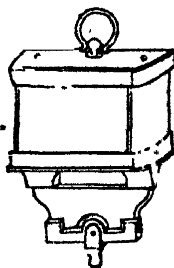
The magnetic or black oxide of iron, Fe_3O_4, sometimes called the *lead-stone* or loadstone, is estimated as one of the most valuable ores of iron, because it enjoys the property, when freely suspended, of pointing to the north; and it does this by virtue of an inherent property which belongs to it, called magnetism.

The loadstone occurs native, and crystallizes in cubes, and is said to have been discovered by a shepherd on Mount Ida, who first noticed that the iron of his crook was attracted by it. (Fig. 316.)

The magnet was not only called *magnes*, but "lapis Heracleus," from Heraclea, a city of Magnesia, a part of ancient Lydia, in Greece. It is also called *lapis nauticus*, because of its use in navigation; and *siderites* because the mineral attracts iron, which the Greeks called σίδερος.

"The earliest mention in English records of the primitive mariner's compass is that by Alexander Neckham, who describes the same in his 'Treatise on Things pertaining to Ships.' Neckham was born at St. Albans in 1157. A translation of his works, from the Latin, was published in 1866. In the reign of Edward III., the magnet was known by the name of the *sail-stone* or *adamant*, and the compass was called the sailing-needle or dial, though it is long after this period before we find the word compass. A ship, called the 'Plenty,' sailed from Hull in 1338, and we find that she was steered by the sailing-stone. In 1345, another entry occurs of one of the king's ships, called

the 'George,' bringing over sixteen horologies from Sluys, in Normandy, and that money had been paid at the same place for twelve stones, called adamants or sail-stones, for repairing divers instruments pertaining to a ship."


FIG. 317.
A mounted Loadstone.

Fine large pieces of loadstone are usually mounted in handsome brass or silver boxes, and were highly prized in the reign of King Charles II., when the Royal Society of England began to exert itself in the acquisition of scientific knowledge.

When examined with a magnetic needle, the mineral is found to have two points where the magnetic virtue exists in the greatest intensity: these are called poles, and are connected with the pieces of soft iron which protrude from the case containing the loadstone; they take off the friction and wear and tear of the mineral, whilst all cutting of the stone, in order to obtain a hollow space between the two poles, as in an ordinary horse-shoe magnet, is avoided. The magnetism from the loadstone is easily conferred upon and retained by hardened steel.

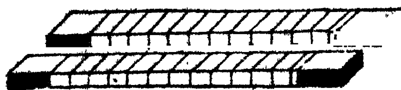
FIG. 318.—*Two Bars of Steel,*
Each marked N and S at their opposite extremities, and connected by pieces of soft iron, called "feeders."

It is only necessary to rub the steel or drag the loadstone round in one direction, taking care to put the pole N of the latter on the end of the steel bar marked S. An assemblage of steel plates in the form of an elongated horse-shoe, when carefully magnetised and fixed together, constitutes a kind of magnetic battery having greatly increased powers. (Fig. 319.)


FIG. 319.

This would be called a compound horse-shoe magazine or battery, composed of an odd number of horse-shoe bars of different lengths. The union of unequal bars produces a step-like arrangement at the poles, the largest bar being in the centre, with the pair of bars next largest on each side, and so on progressively. This peculiar arrangement, with all other magnetic instruments, may be obtained from Elliott, Charing Cross, and possesses several advantages, especially when used to confer magnetism on other pieces of steel.

The magnets (Fig. 320) bearing the name of Scoresby are composed of many magnetized, laminated-steel plates, combined together so as to act uniformly as one bar, by which means a powerful magnetic arrangement is obtained. A piece


FIG. 320.—*Scoresby's Magnets.*

of steel, usually called a needle, when carefully balanced and suspended on a sharp point with a central hard metal cap, and then magnetized, is called a magnetic steel needle.

FIG. 321.

It is extremely useful for showing the influence of the magnetism of the earth as regards the horizontal-directive force, and is absolutely necessary in showing a repetition of the facts already explained in the article on "Static Electricity" (page 212), viz., that just as similar electricities repel, and opposite ones attract, so a north pole of a magnet repels the north pole of the magnetic needle, and the south behaves in a like manner with the south pole of the needle. Dissimilar magnetisms attract, therefore, the north pole of a bar magnet; one of those, shown at Fig. 318, will attract the south pole of the needle, and *vice versâ.*

At Elliott's may be obtained magnetic needles suspended in a beautiful manner, so that the needle moves either in a horizontal or in a vertical plane. When the needle moves in the horizontal plane, it is an ordinary mariner's compass; but when it is free to move in a perpendicular plane, it—however carefully balanced before magnetizing—dips downwards, and points to the earth like a finger-post, directing the eyes of the student to the terrestrial power of magnetism which causes the "dip."

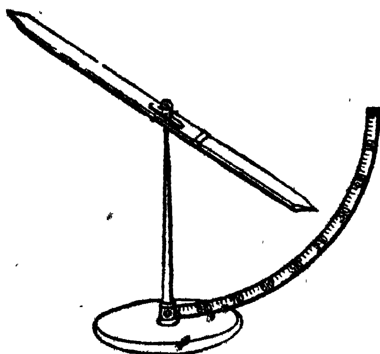


FIG. 322.—*Needle suspended, and dipping towards the Earth.*

The direction of the horizontal magnetized needle not only varies daily, called "diurnal variations," but it has changed during various periods of years. The magnetic needle does not point due north and south, but in a plane or

direction peculiar to itself, called the magnetic meridian, to distinguish it from the true or terrestrial meridian. Magnetic meridian lines are planes passing through the centre of the earth in the direction of the magnetic needle. The terrestrial meridian is the plane passing through the same place on the axis of the earth.

The angle made by these two planes is called the *declination of the needle*. It is determined by measuring the angle which the direction of the needle makes with the meridian line. The declination was eastward at the beginning of the 17th century; it was zero, or 0, in 1660, *i.e.*, the needle pointed due north and south. The declination now changed to the westward, and had increased to 24° 30′ in the year 1818, since which period it has steadily retrograded, and about ten years ago had reached 21° 48′ in London.

It would appear from the observations set on foot many years ago by General Sabine, that the sun and moon are magnetic, and do affect the needle in its diurnal movements.

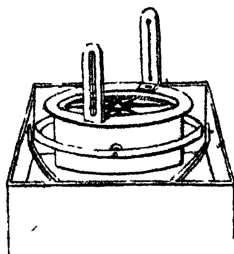


FIG. 323.

The marine compass only differs from the ordinary one in being suspended in such a manner that the motion of the vessel shall not disturb its horizontal position. The marine azimuth compass (Fig. 323) is a more elaborate mariner's compass, having within the circumference of the inner box sights for determining the angular distances of objects from the magnetic meridian, and being hung in detached gimbals.

The dipping needle or inclination compass is also found to vary as the dip increases, as might be expected, the nearer we approach to the north pole. At a point in 70° 5′ of north latitude and 96° 46′ west longitude on the west coast of Boothia Felix, a place was discovered by Captain Parry (the north magnetic pole) where the dipping needle became vertical, and the horizontal compass ceased to move right or left, or traverse. Captain James Ross discovered the other end of the great terrestrial magnetic power, the south magnetic pole, to be about latitude 73° south and longitude 130° east.

The student may realise such movements of the dipping needle by laying one of the bar magnets (Fig. 318) in the centre of a sheet of cardboard on which a circle has been described.

On moving the dipping needle round the circle, it will be found to take the vertical position at the poles A A, whilst it becomes horizontal at the equatorial position B B, *i.e.* midway between the north and south pole.

The inclination or dip varies like the horizontal declination. At London, it was 70° 27′ in 1720, 69° 2′ in 1833, and 68° 51′ in 1849; at the present time it is about 68° 30′.

The earth being virtually an enormous magnet, whose north pole is in the southern hemisphere, and *vice versâ*, must affect all ferruginous matter on the earth by induction.

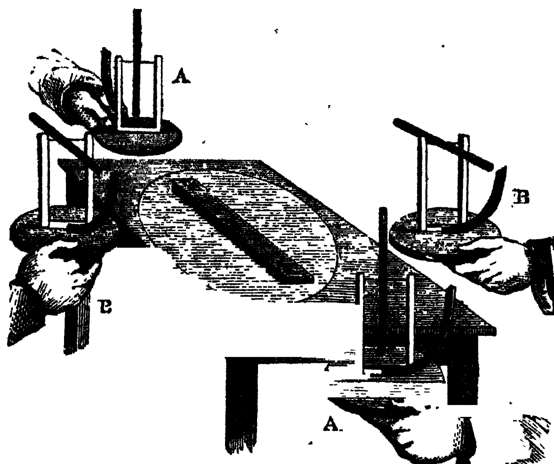


FIG. 324.

It was stated, in the article on Electricity, that the term induction would have to be used again; and the student is reminded that this is defined to be the magnetic influence set up by the mere neighbourhood or proximity of a body—the earth, or the loadstone, or a magnetized steel bar—having or possessing the magnetic virtue or force.

By placing variously shaped pieces of soft iron near a powerful magnet, they are supported or attracted so long as the magnet is kept sufficiently near them; but, as the distance is increased, they drop off one by one.

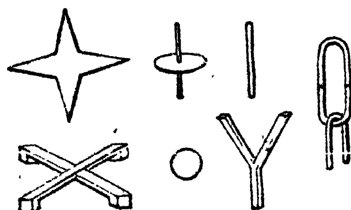


FIG. 325.—*Variously shaped pieces of soft Iron for showing Induced Magnetism.*

The magnetic power so quickly conferred on soft iron is as rapidly lost when it is removed from the disturbing cause, reminding one of conductors of electricity, which cannot maintain polarity; whereas steel, which acquires magnetic power more slowly, retains it with a tighter grasp, and, like non-conductors of electricity, glass, wax, &c., can maintain magnetic polarity.

On the supposition that all terrestrial magnetism has an electrical origin, and is produced by currents of electric force which circulate around the globe, a very pretty piece of apparatus is constructed, consisting of a distribution of wires, covered with silk, over a terrestrial globe in parallel lines of latitude.

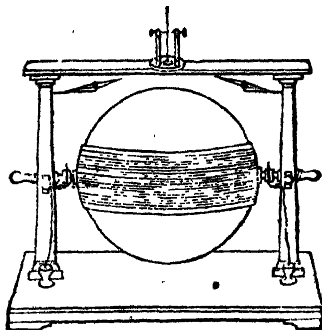


FIG. 326.—*Model made by Elliott,*

Showing that electrical currents circulating around a globe produce magnetic currents.

The dipping needle and horizontal needle held in different positions on the surface of the globe, whilst the wires are connected with the voltaic battery, give the student a very good notion of the natural directive power of the magnetism that exists over the surface of the earth on which we live, and also illustrates again the "*inductive*" power of magnetic force.

The force which rules the position of the magnetic needle is neither attractive nor repulsive, but simply directive. A magnetic needle floating on a cork neither advances nor moves backward; it simply takes a position nearly north and south, and places itself in the magnetic meridian.

The engraving, Fig. 328, is a correct copy of the photographic curves of the self-registering "Declination Magnetograph," as used at the Magnetic Observatory at Stonyhurst College, near Blackburn.

This is one of a series of magnetic instruments which are self-registering night and day; and it is interesting to notice in the photographic curves the amount of disturbance shown between the 8th and 10th of August, 1868. The instruments are under the charge of the Rev. S. G. Perry, who has most kindly furnished the following drawing and description of the Magnetic Observatory at Stonyhurst:

"An idea of the disposition of the instruments may be formed from the drawing (Fig. 327), and a very brief description will make it still more clear.

"The instruments record the oscillations of three magnets suspended under the glass shades; and we thus get completely all the changes, both as to direction and intensity, in the earth's magnetism. The magnet which is to the right in the sketch is suspended by a silk thread in the magnetic meridian, and, by the aid of a mirror attached to it, describes on a cylinder, which is put in motion by the clock on the centre pier, all the variations in the magnetic declination. The other two magnets give the two components of the total magnetic force of the earth. That which records the variations of the vertical

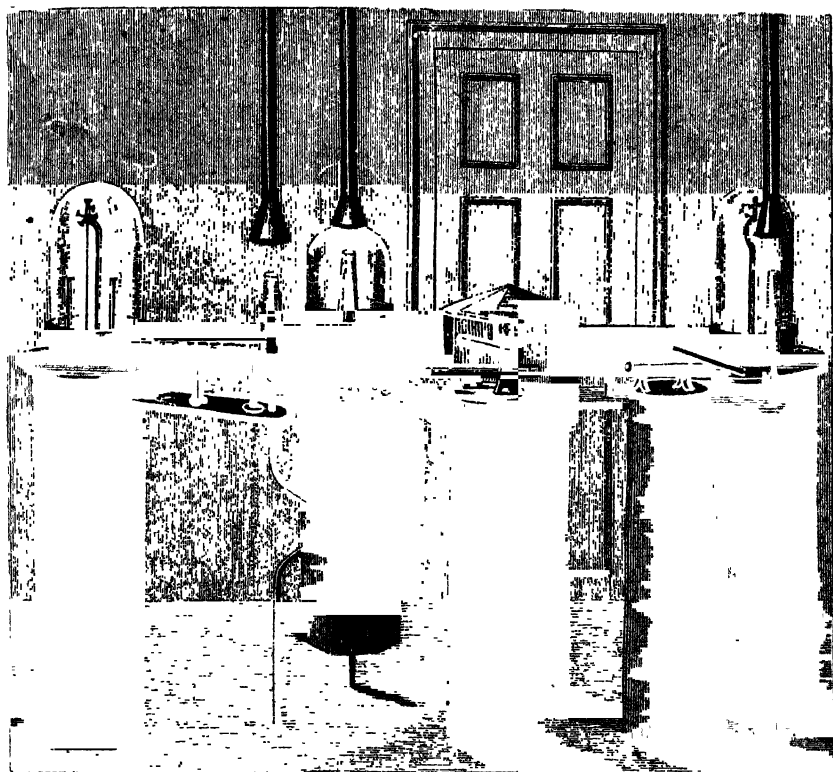


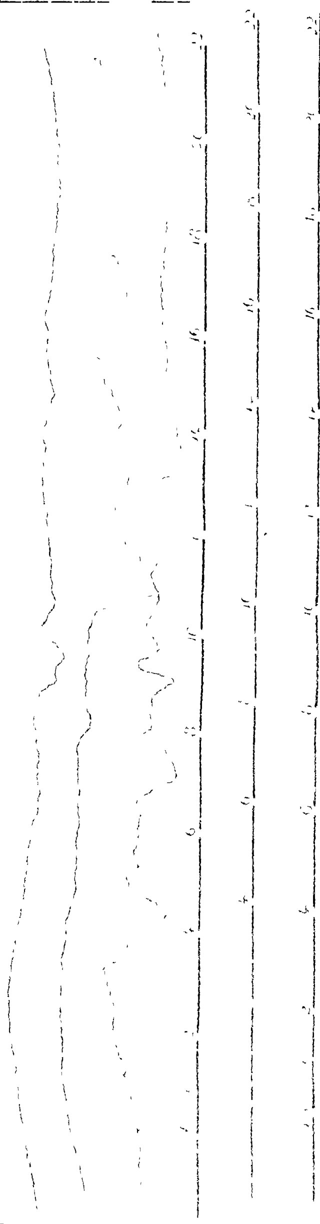
FIG. 327.—*The Magnetic Observatory at Stonyhurst College.*

component rests, under the shade near the doorway, on two agate edges; whilst the horizontal-component magnet is suspended by a double steel thread, under the shade to the left of the picture, and is held nearly at right angles to the magnetic meridian by the torsion of the thread.

"Under the clock-box, which stands in the centre, are the three cylinders covered with sensitive paper. To each magnet is attached a semicircular mirror, which sends the rays from a jet of gas to one of the cylinders in the clock-box, and thus describes, by a curved line, all the oscillations of the magnet. A second semicircular mirror is fastened to the pier on which the instrument stands, and, describing always a straight line on the cylinder which is opposite to it, gives the zero line for the curve.

"These magnetographs were constructed by Mr. Adie, and are similar in nearly every respect to those made for the Kew Observatory, under the direction of Mr. Welch.

"The magnetic room is built underground to prevent sudden changes of


FIG. 328.

temperature, and we have been so fortunate that the daily range is scarcely over 0·2°."

It is curious that every kind of vibration assists the magnetization of iron or steel by terrestrial magnetism. If half-a-dozen iron wires, 12 or 15 in. in length, are twisted strongly together whilst held in the direction of a dipping needle, viz. 68°, they become very magnetic, and, having now distinct poles, will affect a magnetic needle like a steel-bar magnet. Iron columns, guns, the plating of ships of war, cargoes of iron or steel, all acquire magnetic power; and, until this fact was understood and provided for, many disastrous shipwrecks were caused by the compass pointing in the wrong direction, and thus conducting the unfortunate ship to the rocks, instead of keeping her in mid-ocean. Mr. Barlow has devised certain means by which the compasses of ships may be corrected, and the influence of local magnetic attraction, due to the guns, or shot, or other iron or steel cargo, neutralized, so that the "*directive*" force of terrestrial magnetism alone shall guide the ship over the pathless ocean. A late and lamented friend of the writer (Mr. Evan Hopkins) tried a vast number of experiments, and wrote an interesting pamphlet on terrestrial magnetism, with reference to the compasses of iron ships, their deviation and remedies.

It is impossible in our limits to do justice to the arguments brought forward and discussed by Mr. Hopkins; but the remarks made at the termination of the debate at the Royal United Service Institution on his paper will give the reader some notion of the opinions entertained by the meeting on the method of destroying the polarity of iron ships, as proposed by Mr. Hopkins.

"Sir FREDERICK NICOLSON: The subject has been treated in an eminently practical way. In the abstract of Mr. Hopkins's papers, I find that there

is one statement which appears to me the most important, that is, Mr. Hopkins says he is prepared to destroy the polarity of any given ship in ten minutes. The only question I wish to ask, because the gist of the paper lies in that assertion, is whether Mr. Hopkins has performed that operation upon any ship.

"Mr. HOPKINS: No, not in any ship as yet; but I have made experiments on long bars and plates of iron, and I am quite satisfied that I can produce the same results on the iron plates of a ship. In reply to the observations which have been made I will not detain you long, because I do not think the remarks made require lengthy replies. First, with regard to Sir Edward Belcher's remarks, he said that I stated that there was no magnetic pole. I did not state that there was no magnetic pole; on the contrary, I have endeavoured to explain that *the entire areas bounded by the antarctic and the arctic circles are the great magnetic poles of the earth*, towards which all the magnetic meridians converge. I do not mean to say for one moment but that a dipping needle at the north latitude of 70° approached nearly 90°, observed by Sir James Ross, and probably over a great number of square miles in that region; but I have seen dipping needles approaching 90° near the equator. There are many places in the islands of Scotland, also in Norway, Sweden, and Russia, where the dipping needle will not only approach 90°, but remain at 90°. Therefore I repeat that the dip of the dipping needle does not necessarily depend on the action of the terrestrial pole, but on local attraction. Besides, neither experiments, analogy, nor observations on the magnetic meridians support the notion of the magnetic pole being merely a mathematical point near Boothia Gulf. We have only to prolong the observed magnetic meridians to the circle of 70° of latitude to show the fallacy of the Boothian pole. We must be guided by the *meridians* of the needles to determine the position of the active polar areas. Go to Norway; go to Sweden; where do the needles point? Do they point to Boothia Felix? No; they do not. They point towards the arctic region, and not to any special *point*. With regard to the other point that Sir Edward stated with reference to the compass, I do not believe there is a possibility for the compass to point correctly unless it be left entirely under the control of the great terrestrial force: any interference, whether by magnets or electric appliances, can only increase the confusion and danger, and therefore the compass should not be tampered with, but left to act freely and under the sole influence of terrestrial magnetism. With regard to what Captain Selwyn stated about the steering compass. He said, 'Never mind that; I believe you do not care much for the steering compass; you go by the standard compass.' Well, there is now always a difference between the standard and the steering compasses. We know that in iron ships that difference constantly varies. You do not know what the variation is that is constantly going on. Were you certain of the exact amount of variation, it would be like the watch and chronometer spoken of by Captain Selwyn; but you cannot compare the case of your watch and chronometer with those of the standard and steering compasses when you have an iron vessel, and where you have a perpetual change going on in the action of the polarity of the iron vessel. With regard to the reflector, I see Captain Selwyn apprehends difficulty. I see none, and the appliance is already appreciated by several experienced captains. I do not think there would be much difficulty in seeing a compass, with a good strong light, with a 12-inch card at a distance of even 30 feet. However, I leave that to others. There is one thing Sir Edward Belcher mentioned with regard to the needles. I am perfectly

familiar with all the needles they use in high latitudes. They are utterly worthless in *directive* power. As to the dipping needles, they have no directive power whatever, and, as justly observed by Captain Fishbourne, have no lateral directive power at all, and cannot therefore serve as guides to determine questions connected with *meridian lines*. The *curved* magnetic needle will act where neither the straight nor the dipping needles can be rendered serviceable in high latitudes. It only remains for me, in conclusion, to thank you for the patience and kindness with which you have listened to the observations I have made.

"The CHAIRMAN: I am sure there will be but one opinion among you as to a vote of thanks to Mr. Hopkins for the very interesting paper he has read. He has brought forward some of the old ideas relating to magnetism, which many here were not acquainted with, and he has given us some new ideas. I must say that his idea with respect to the bent needle is one which I think is deserving of a trial. I must also say I should like to see that dissipation of the polarity of a ship tried, although I am afraid that the soft iron of the ship would become magnetised by some other extraneous cause at present unknown. I really believe this, although we are very thankful to him for what he has told us, that we shall still find it positively necessary to have recourse to observation. I hope what you have heard to-night will strengthen your confidence in the compass as a means of steering. There is another remark about the pole. As I have passed within 70 miles of it, and the dip was 89° 47″, I must say that I can only look upon the pole as capable of being defined, not perhaps exactly as a point, but very nearly as a point, because as I passed up, I changed from 89° 47″ north dip to 89° 46″ south dip. With respect to the deviation of the compass, it has been an old thing with us who have been in high latitudes. We know perfectly well that we suffer the same inconvenience which is experienced now in iron ships. In Behring's Straits, in going about there, the deviation of the ship amounted to six points of the compass; and I can say, which I have no doubt Captain Maguire will corroborate me in, that we should have had the greatest difficulty in the world to take our ships up into the position we did, if it was not for the admirable charts of Admiral Bechey, and in which expedition Sir Edward Belcher served. There is only one other point. I will say that I have listened to this paper with a great deal of gratification and pleasure, because, during the course of my service in the Arctic regions, it so happened that for two years I was not able to use a compass at all; therefore, I am able to appreciate anything that will increase the value of it."

The sequel is soon told, for Mr. Hopkins caught a violent cold whilst engaged in attempting to depolarise one of the iron-clads; and, although he partially recovered, his system received a shock which ended in death. His kind and enthusiastic spirit was spared the disheartening report of the non-success of his method, subsequently brought before the Royal Society.

Mr. Barlow corrects the local magnetic power of the iron of the ship by placing a piece of soft iron in a particular position, so as to compensate for the derangement of the compass produced by the anchors, chains, guns, &c., of the vessel.

Amongst the latest practical applications of magnetism to useful purposes is that of Mr. Saxby, who proposes to test the iron of guns by magnetic power. Mr. Paget, C.E., in a very able paper in "The Engineer," thus reports on the process or method of Mr. Saxby for testing iron:

"It is well known to engineers that it is a most difficult and often impossible thing to find out the existence of a false weld in a forging, or of a blowhole or honeycomb in an iron or steel casting. The only safe way of doing this is by carefully measuring the elongation of the piece under a given load, as with a false weld all the work is thrown on the diminished area at the defective weld, and the thicker parts are scarcely extended by the force which is perhaps rupturing the bar at the flawed spot. It need scarcely be said that there are many important cases where this process, or the equivalent but dangerous one of trying the effects of an impulsive force, could neither be mechanically nor commercially practicable. Every one knows that a simple method by which internal flaws and solutions of continuity in constructive details could be easily detected would be of enormous value to the world. Such a method has undoubtedly been discovered by Mr. S. M. Saxby, R.N., who has very judiciously been allowed by the Admiralty, during the course of this year, to experiment with it in the royal dockyards. Though comparatively new, and not yet completely worked out, the process will possibly have a yet more extended application than finding out only mechanical flaws in iron, and possibly in cast iron and steel.

"The principle upon which Mr. Saxby's method is founded is so simple that it certainly seems strange that it had previously escaped notice. It has been known for nearly a century and a half that when a bar or any mass of soft iron is placed in the position of the dipping needle, it is at once sensibly magnetic, the lower extremity being a north pole in our latitudes, and the upper extremity a south pole. In the southern hemisphere the poles are of course reversed. The same action, only weakened, takes place in a bar hanging in a vertical or any other position; only the effect is weaker the more the position of the longitudinal axis of, for instance, a long bar departs from that of the magnetic dipping needle.

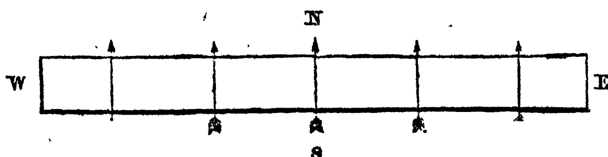


FIG. 329.

"When, therefore, as in Fig. 329, a small compass needle is slowly passed in front of a bar of very good iron, placed in an east and west direction, the needle will not be disturbed from its proper direction, which is of course at right angles to this, or north and south.

"All this refers to regularly homogeneous bars of best quality—to bars without any mechanical solutions of continuity. With internal flaws or interruptions of continuity the bar is no longer regularly magnetic. It has long been known that a good compass needle, or a good permanent magnet, must be homogeneous and without flaws in order to take and retain its maximum amount of magnetism. In a word, *any mechanical solution of continuity is accompanied with a polar solution of continuity*, and the given bar or mass with flaws—whether permanently magnetized or temporarily so by the induc-

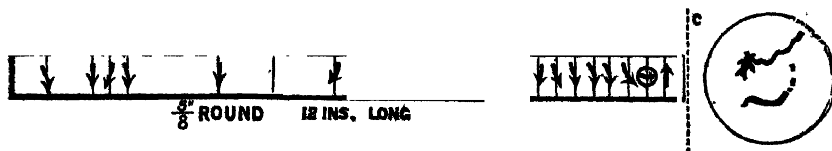


FIG. 330.

tive action of the earth—is no longer one regular magnet, but several different magnets, with the different magnetisms separated from each other. The delicately-poised magnet of a compass can thus be made to tell the presence of such solutions of continuity. The above drawing (Fig. 330), showing the actual results of the test with a $\frac{5}{8}$ in. bar, 12 in. long, will illustrate the manner in which the compass magnet is affected by the presence of cracks, of solutions of continuity, in the bar, which is supposed to be lying in the equatorial magnetic plane, or east and west.

"By the enlightened permission of the Admiralty Board, Mr. Saxby, as stated, has already been allowed to test his method in various ways in the royal dockyards of Sheerness and Chatham, and we will describe some of the practical results of these experiments. Amongst these were a number of very remarkable trials conducted in the presence of the master smiths, the foremen of the testing-houses, and several of the chief engineers of the royal navy.

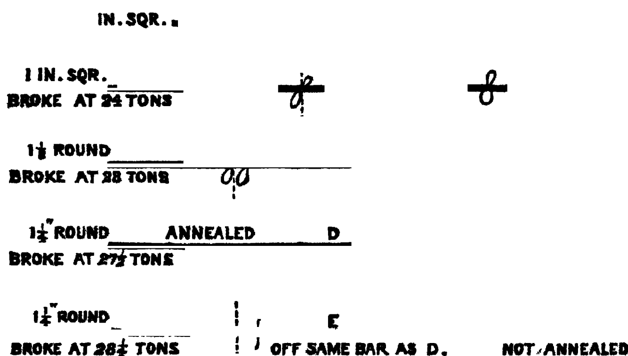


FIG. 331.

Mr. Saxby, for instance, was requested to find out the weakest spots in a number of bars, and to tie a string or make a chalk mark on each spot. Immediately afterwards all these bars were put into the testing machine and broken. Their history is given above, in the annexed cuts (Fig. 331), the prediction having in every case been verified. The bars are shown by lines to scale, and a scroll is placed where the weakest part was found out by the needle. The vertical dotted lines indicate the spots where the several bars broke.

"The smiths of the royal dockyards seem to have properly tried Mr. Saxby's powers in almost every possible way, and most ingenious devices were some-

times resorted to for the purpose. As examples out of many, in the centre of a bar (Fig. 332) of 1 in. square forged iron was welded a piece of unmagnetized steel about 5 in. long. The needle detected a fault at about the centre of the piece of steel.

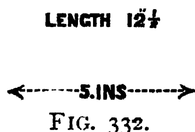


FIG. 332.

"Now Mr. Saxby's method can detect the presence, and negatively of course the absence, of small or large solutions of continuity. It can detect false welds, smaller flaws caused by bad workmanship or wear, and, we believe, what is commonly termed 'crystallization,' which will, probably, at once be generally acknowledged to consist in a disruption or parting of the facets of the amorphously arranged crystals of which iron is built up. It can, of course, only detect the results of the chemical constitution of iron, as evidenced in the less perfect cohesion of the crystals when alloyed, in relatively considerable quantities, with foreign bodies. There is little doubt that the magnetic method is a test of the homogeneous character of the iron and of its freedom from fissures and cracks, and so far it undoubtedly forms a test of quality. It will appear scarcely credible that a common pocket-compass needle should be able—almost like the divining rod said to be used for finding out springs of water—to discover important defects in large iron bars. A mere statement of the fact does sound almost incredible until the simple means actually employed are explained."

Amongst the influences which open the pores of the steel, as it were, to receive a full charge of magnetic force is that of heat, and it is found that when steel is made red hot, and allowed to cool in the direction of the magnetic dip, it acquires more quickly and largely the magnetic charge.

It was contended by Mrs. Somerville that unmagnetized needles were magnetized if exposed to the violet ray of the spectrum; but Riess and Moser have shown that these effects only take place when the needle is perpendicular to the magnetic meridian, facilitated by the heating of the needle, first by exposure to the violet rays, and secondly and more especially by the subsequent cooling.

A powerful steel magnet, heated to a white heat, loses its magnetic power. Red-hot iron is no longer rendered magnetic by induction.

Nickel, raised to the temperature of boiling oil, loses its magnetic virtue.

It ought to be mentioned here, that certain metals, nickel and cobalt, have distinct magnetic powers; and Sir Charles Wheatstone has given a very ingenious and elegant method of detecting minute quantities of magnetic force. He says—

"If a short sewing needle, A (Fig. 333), the eye end being broken off, rest upon its point on the polar surface of a powerful bar magnet, it will generally take a position inclined to the surface; but a locality may generally be found in which the needle will stand nearly vertical; this point may be ascertained by placing a piece of unglazed paper, D, between the needle and the magnet, and moving it about until the vertical position of the needle is obtained.

"If we elevate the paper and needle above the magnet to the greatest

distance at which the needle will remain vertical, it becomes to the last degree sensitive of magnetic force; so that by bringing specimens of nickel or cobalt, which have the least magnetic power, or any impure metal, such as a specimen of metallic manganese, which Faraday thought he had proved (when entirely free from iron) does not indicate the slightest magnetic power,* or rhodium, iridium, or hammered brass, if the latter metals contain any iron, they will affect Wheatstone's test needle, but not otherwise."

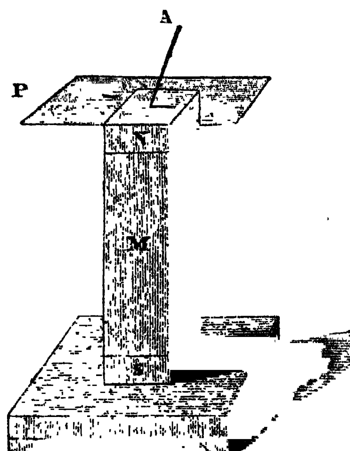


FIG. 333.

There are other influences that may affect the magnetic needle. When a plate of copper is rotated quickly (say 800 revolutions per minute) beneath a suspended magnet, the latter also is thrown into rapid rotation.

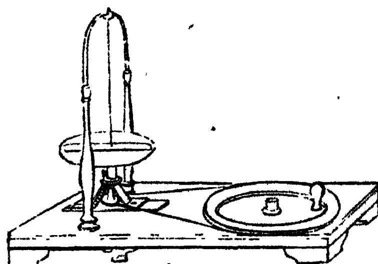


FIG. 334.

It might be thought that this was brought about by the motion of the air; but the same effect occurs even when the copper plate rotates in a vacuum, or is wholly screened by glass from the magnetic needle.

* See Dia-magnetism, for further information.

The apparatus (Fig. 334) exhibits this curious property of metallic plates in motion, and is usually made by Elliott with a variety of metallic plates, all of which, when spun round rapidly, first cause the magnetic needle to deviate from its natural position, and then finally to assume rotation.

When the experiment is reversed, and a compound bent magnet is caused to revolve with great velocity about its axis of symmetry, and below the metallic plate, which is carefully suspended, then the latter commences revolving in the same direction.

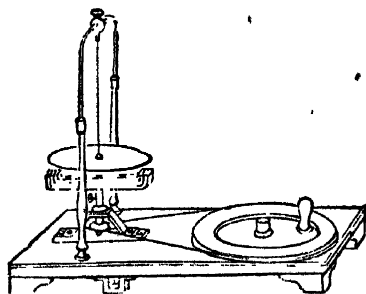


FIG. 335.

All these experiments have arisen from the original one performed by Arago, who first tried the effect of a ring of copper upon the oscillation of a delicate magnetic needle which it enclosed. In free space the magnet performed 420 oscillations before it reached an arc of 10°, whereas, when surrounded with a copper ring, they were reduced to fourteen oscillations; under the same circumstances in a ring of wood, the oscillations were reduced from 420 to about 300.

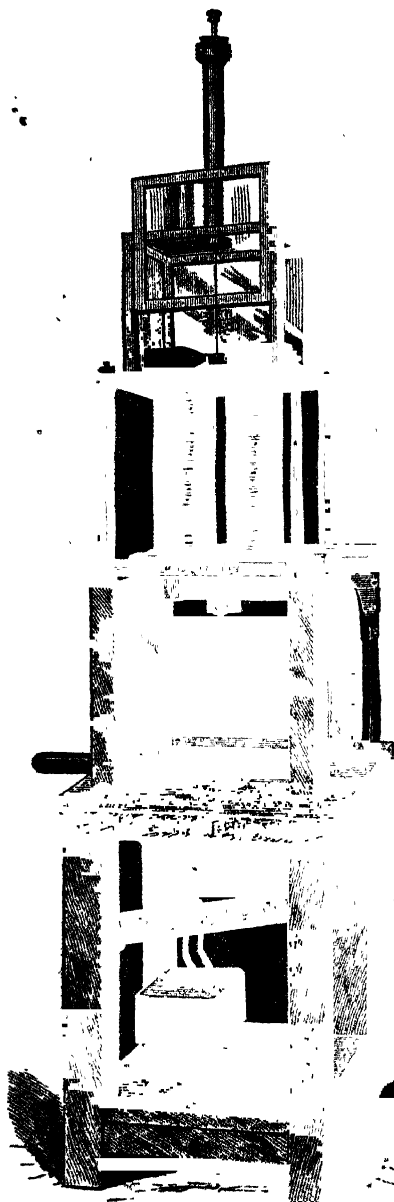


FIG. 336.
Apparatus made by Mr. Apps,
Which may be used either for dia-magnetic experiments or to show the enormous weight which can be supported by a powerful electro-magnet.

DIA-MAGNETISM.

In the preceding chapter, it has been pointed out that the loadstone, iron and steel, cobalt and nickel, possess ordinary magnetic powers, and can attract or repel a magnetic needle. We have now in the beautiful experiments first made by Faraday to consider the magnetic powers of other substances, and shall discover that a vast number of bodies are affected by magnetism when produced by and circulating from pole to pole of a very powerful electro-magnet, such as that depicted at Fig. 336.

The dia-magnetic apparatus is specially designed to illustrate Faraday's celebrated experiments on the dia-magnetism or para-magnetism of bodies, and the effect on light in the rotation of the plane of the polarized ray, &c.

Besides these very extensive and varied applications, the actual lifting power of the electro-magnet is easily found by turning the poles downwards, when they face the armature connected with the compound-lever arrangement. The power obtained with a single cell of Bunsen's, of very small size, will lift 5 cwt., and with twenty Grove's cells this magnificent apparatus will lift 3 tons. It was exhibited before the Royal Society, April, 1868.

In the experiments, which will presently be detailed, there are certain positions constantly referred to, *i.e.*, the positions which various bodies may assume between the poles of the electro-magnet (Fig. 336). Thus the space between the two poles is called the magnetic field, and a straight line drawn from pole to pole, like the poles of the earth, is called the axial line, similar to the imaginary line around which the earth rotates, called its axis. Any body subjected to the action of the magnetic current is said to place itself *axially* when it takes the above direction. If, however, the body under experiment takes a position at right angles to this direction, it is said to point *equatorially*. Thus, in Fig. 337, the poles are represented by pieces of soft iron bevelled

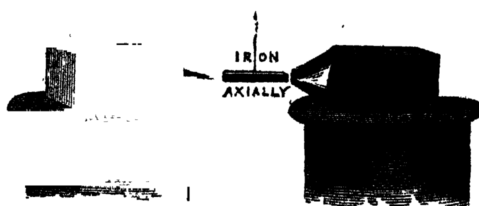


FIG. 337.

off to a rough point; and if a rod of iron is suspended between them and the electro-magnet connected with the battery, the rod takes up an axial position, whilst a similar rod of bismuth, also suspended by a filament of silk, places itself at right angles to that position, as is shown at Fig. 338.

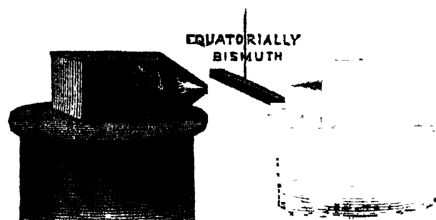


FIG. 338.

In all these experiments the poles of the magnet, with their soft-iron armatures, are surrounded with a glass box, like the lantern of a balance, to prevent the action of currents of air. Faraday discovered that when the crystals or solutions of salts of metals that are magnetic, such as ferrous sulphate, are placed in a glass tube which is not magnetic, they do, as a general rule, place themselves axially. Cobaltous and nickelous sulphate behave in the same manner; and this axial position is always maintained, provided the metal enter into the *basyl* of the salt.

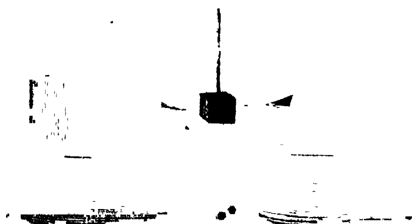


FIG. 339.—*The Cube of Bismuth taking the Equatorial position.*

When a single pole of the electro-magnet is used, repulsion takes place with very many bodies, and, of course, if the substance is repelled by both poles when placed in the magnetic field, it will take a place at right angles to the magnetic current, or the equatorial position.

Phosphorus, bismuth, and antimony—the first a non-conductor of electricity, and the second and third metals therefore conductors—are each and all repelled from a single pole, or place themselves in the equatorial position between the two poles.

It is most amusing to twirl a suspended halfpenny between the poles of the electro-magnet (Fig. 340). Of course this may be done as often or as long as the experimenter pleases; but if, whilst the coin is rotating, the electro-magnet is connected with the battery, the halfpenny stops dead, and instantly places itself in the equatorial position.

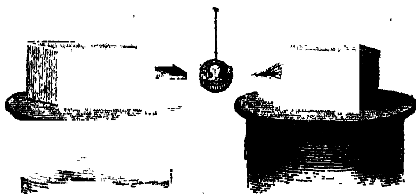


FIG. 340.—*The Halfpenny twirled, then stopped by the magnetic force.*

The preceding experiments show that those bodies which are not magnetic will exhibit dia-magnetic properties, *i.e.*, they are substances through which the lines of magnetic force (represented by the beautiful curves assumed by iron filings when sprinkled on a sheet of cardboard held over the poles of a powerful magnet or, still better, an electro-magnet) pass without affecting them like iron, cobalt, or nickel.

This mode of experimenting is more delicate as a test for magnetism than the use of the needle, already alluded to at page 362, Fig. 333.

And it was by taking solutions of pure salts of manganese and chromium, and placing them in the magnetic field, that they were discovered to be magnetic, whilst as metals it was so difficult, if not almost impossible, to obtain them in the pure state and free from iron. (Fig. 341.)

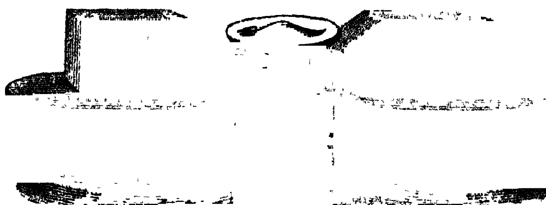


FIG. 341.

Faraday, always so exact and orderly in his classification and nomenclature, proposes to include all the phenomena under one general title, viz., that of magnetism, and to subdivide this into para-magnetic and dia-magnetic phenomena. A very long list, originating with Faraday, has therefore been framed on this principle.

Para-Magnetic, usually called Magnetic. Axial.	Dia-Magnetic. Equatorial.	Para-Magnetic, usually called Magnetic. Axial.	Dia-Magnetic. Equatorial.
Manganese	Lead	Sulphate of zinc	Litharge
Nickel	Cadmium	Shellac	Phosphorus
Cobalt	Sodium	All sorts of iron,	Common salt
Iron	Mercury	where the latter	Nitre
Titanium	Zinc	is basic	Sulphur
Palladium	Tin	Vermilion	Resin
Cerium	Bismuth	Tourmaline	Spermaceti
Chromium	Antimony	Charcoal	Iceland spar
Platinum	Arsenic	Oxygen, which	Tartaric acid
Osmium	Silver	stands alone as	Citric acid
Paper	Gold	a para-magne-	Water
Sealing-wax	Copper	tic gas	Alcohol
Berlin porcelain	Tungsten	Salts of chromium	Ether
China ink	Uranium	Salts of manga-	Sugar
Plumbago	Rhodium	nese	Starch
Peroxide of iron	Iridium	Oxide of titanium	Gum arabic
Fluor spar	Alum	Oxide of chro-	Wood
Asbetos	Glass	mium	&c., &c.
Silkworm gut	Rock crystal	Chromic acid.	
Red lead	The mineral acids		

Nitrogen.

Nitrogen is like a vacuum—it is neither para-magnetic nor dia-magnetic; it is, in strict reason, like space, with reference to these experiments; it is a zero, or a starting-point.

The magnetic or dia-magnetic property of a body, curious to say, varies according to the medium in which it is placed: thus, a glass rod, suspended horizontally in water, which we find, with glass, in the dia-magnetic column, points axially, like any ordinary magnetic body; but if the same glass rod is suspended in a solution of ferrous sulphate, a magnetic body, it points equatorially.

The magnetic-field test discovers whether a metallic salt has the metal in the basyl, the basic, or electro-positive state; or whether the metal is simply a part or constituent of the acid or electro-negative compound. Iron is basyl in ferrous sulphate, and sets axially, and is para-magnetic; but in potassic ferrocyanide it forms part of the ferrocyanic acid, and therefore the crystal sets equatorially, and is dia-magnetic.*

The reader will find all the apparent exceptions and peculiarities attending their structure in Tyndall and Knoblauch's paper (Phil. Mag., 1850, vol. xxxvi., p. 178, and xxxvii., p. 1). The same gentlemen have discovered that dia-magnetic repulsion is as the square of the intensity of the current; and Reich, Weber, and Tyndall seemed to have proved that which foiled Faraday, viz., that bodies under dia-magnetic influence exhibit polar characters. The polarity is the reverse of all other polarities, electrical or magnetic: the feeble polarity of a dia-magnetic substance is the *same* as the pole of the magnet in its neigh-

* The same test will discover, for instance, in a roll of paper, whether it contains iron or not: if it contains the metal, or is coloured blue with cobalt, it will set axially, because iron and cobalt are magnetic, or, to use Faraday's phraseology, para-magnetic.

bourhood; whereas we have learnt that north induces south magnetism in a piece of iron, and vitreous electricity induces negative in the body to which it is approached.

The dia-magnetism of gases was first shown by Father Bancalari, of Genoa, who discovered that flame, such as the flame of a candle, was influenced by the poles of a powerful electro-magnet.

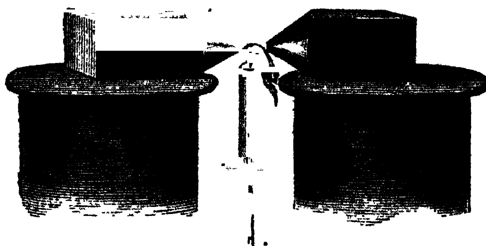


FIG. 342.—*Effect of the Poles on Flame.*

Faraday tried Bancalari's experiment, and found that when the axial line of the magnet was horizontal, and the flame of a taper held near it, and on one side or the other, with about one-third of the flame rising above the level of the upper surface of the poles, the flame seemed to be repelled away from the axial line, moving equatorially until it took an inclined position, as if a gentle wind was acting upon it, and causing its deflection from the perpendicular line.

It was the flame experiments which led to the discovery of the magnetic property of oxygen, and of the dia-magnetic properties of atmospheric air, nitrogen, hydrogen, coal gas, olefiant gas, &c.

Faraday showed that soap-bubbles, filled with various gases and blown from the end of a capillary tube, were either attracted or *repelled* according as the gas was magnetic or dia-magnetic.

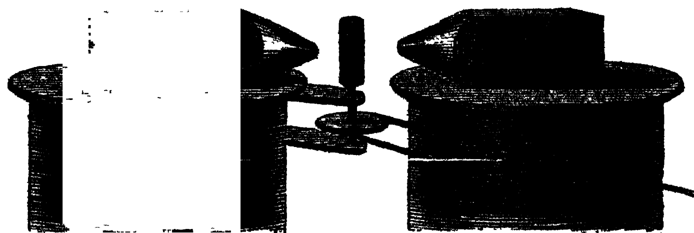


FIG. 343.—*Melting Fusible Metal between the Poles of the "great" Electro-Magnet.*

One of the most curious experiments which may be performed with the dia-magnetic apparatus is that of overcoming the equatorial or para-magnetic force by physical power. The twirled penny-piece brought to rest between the poles, if forcibly turned round, will by the motion generate heat, and may be made very hot.

If a brass tube, containing some solid fusible metal, composed of two parts by weight of bismuth, one of lead, and one of tin, with a few drops of mercury, is rotated very fast by a whirling-table wheel between the poles of the powerful magnet, no effect is produced until contact is made with the battery, and then the rotation or motion is speedily converted into heat, and the fusible metal is melted as if it had been held over the fire. Here again is a perfect *conservation of force*. The heat which melted the alloy is the exact equivalent of the chemical power of the battery used, although it acts by an intermediate force, viz., magnetism; but the chemical action produced the electricity, the current electricity produced the magnetism, and, the magnetic force which tends to keep the bismuth in the alloy in the equatorial position being overcome and resisted by physical force, the muscles of the arm acting on the whirling table eliminate heat.

Faraday thought he had proved, by using heavy glass and permitting a ray of polarized light to pass through it, that the ray was affected by the powerful magnetic force eliminated from the great electro-magnet. Faraday's glass consists of a mixture of silicate and borate of lead, and is much denser than ordinary glass. If a ray of polarized light is allowed to pass through it, and is then examined in the ordinary manner with an analyzing plate or a bundle of plates of glass, or by a tourmaline or a Nicol's prism, the light, of course, disappears, as already explained in the article on Light, when the plane of reflection from the analyzing plate is at right angles to the plane of polarization. (Fig. 344.)

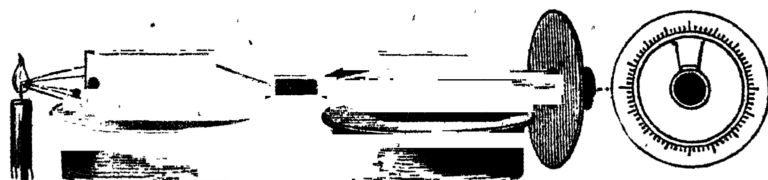


FIG. 344.

If now the battery is connected with the electro-magnet, between the poles of which the bar or cube of Faraday's dense glass is placed, the light re-appears instantly, again disappearing when contact is broken with the battery.

Matteuchi found that the effect was increased by increasing the temperature of the cube of heavy glass to 600° Fahrenheit; and he also ascertained that by subjecting the heavy glass to pressure he could change the direction of the ray of polarized light, as Faraday had done. So that, in fact, Faraday was wrong; the magnetic force did not act upon the ray of polarized light, but on the molecules or particles of the glass, which were under a strain during the time they were subjected to the action of the powerful electro-magnetic force.

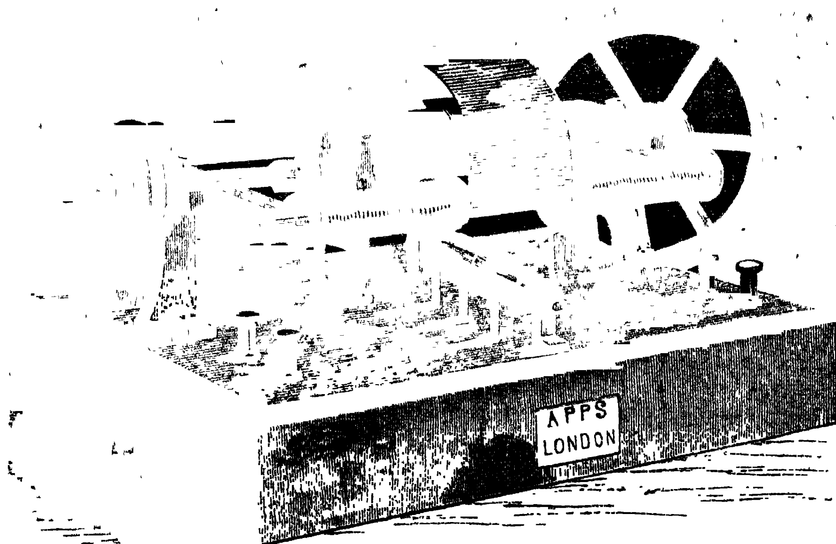


FIG. 345.—*Apps's half-horse power Electro-Magnetic Engine.*

ELECTRO-MAGNETISM, MAGNETO-ELECTRICITY, THERMO-ELECTRICITY.

In 1820, Œrsted, a Danish scientific man, discovered the connection between electricity and magnetism. It was not found where philosophers sought for it. They thought to imitate Nature; and as some steel knives were found to be powerfully magnetic after a discharge of lightning had passed through a box containing them, they subjected other pieces of steel to the discharge of powerful Leyden batteries without producing the effect they expected.

Œrsted found that the electricity must be in motion, or in a dynamical state, such as it would be in when evolved from the voltaic battery.

Static electricity will, under certain arrangements to be hereafter described, magnetize steel; but the mere fact of allowing a wire charged with statical electricity (the force from the electrical machine) to approach a magnetic needle does not affect the needle like the same wire conveying a current from a single voltaic circuit or, still better, a battery.

M. Ampère, who took up the subject directly after Œrsted had published his discoveries, laid the foundation of the science of electro-dynamics. He discovered that every part of the whole circuit—the wires, the terminals or poles, the battery, in fact, all parts—exercised a magnetic power upon the magnetic needle. He also proved that the force was in an eminent degree one of *circulation*. Ampère made himself fully understood by asking his readers to conceive a man lying down in the circuit, so that the wire lies along his face

and body. We are now to suppose that the current enters the wire at his feet and goes out at his head, and that his upturned face and eyes are directed to a magnetic needle suspended parallel with and over the wire conveying the electric current, so that the north pole of the needle points to his face. Directly the current passes, the needle is deflected to his left hand; and by reversing the direction of the current, and causing it to flow into the wire at his head and out from his feet, the needle will now move to his right hand.

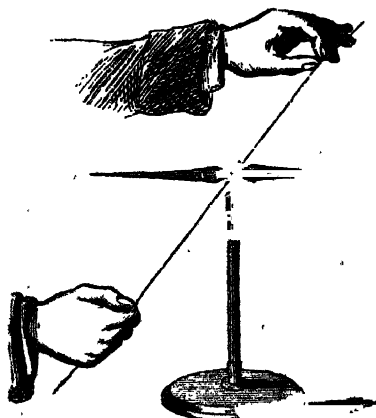


FIG. 346.—*Wire conveying a Current of Electricity affecting the Magnetic Needle.*

Thus every possible variation may be imagined as long as we maintain the same relative positions of the wire and the human body; and it was further ascertained that the intensity of the electro-magnetic force is in the inverse ratio to the simple distance of the magnetic needle from the current; or, in other words, that the elementary action of a simple section of the current upon the needle is in the inverse ratio to the square of the distance.

If a single wire can affect a magnetic needle, it is evident that by doubling and trebling the wire, or winding it round in a helix, the effect must be enormously increased, provided the coils of wire do not touch each other, or are covered with some non-conducting material, such as silk or cotton; hence it is that coils of wire are constructed so that a piece of soft iron placed

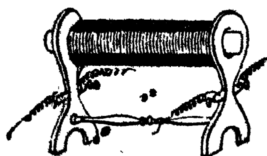


FIG. 347.

inside the core becomes a most powerful magnet directly contact is made with the battery. When the immense power of the electro-magnet was ascer-

tained, great anticipations were formed of the application of this force as a motive power. It is not surprising that this should have been the first conclusion. Thus the great electro-magnet, made by Mr. Apps, that heads the chapter on Dia-magnetism, will lift five hundredweight with a single quarter-pint Grove's cell, and three tons with twenty cells. This conveniently arranged magnet, after being used for dia-magnetic experiments, may be employed for showing the attractive force of the great electro-magnet. It is attached to a lever, which turns it over; and, when suspended with the poles downwards, it is connected with a compound-lever arrangement, on the same principle as railway weighing-machines, and the weights used are one quarter, one half, and one hundredweight.

The writer well remembers the late Prince Consort, on the occasion of one of his private visits to the Polytechnic, putting a question to him as to the rate at which the electro-magnetic power increased or decreased with the distance from the great electro-magnet belonging to the Polytechnic. The attractive force diminishes enormously. Thus, in a paper read by Mr. Robert Hunt before the Institution of Civil Engineers, the following instructive diagram was exhibited:

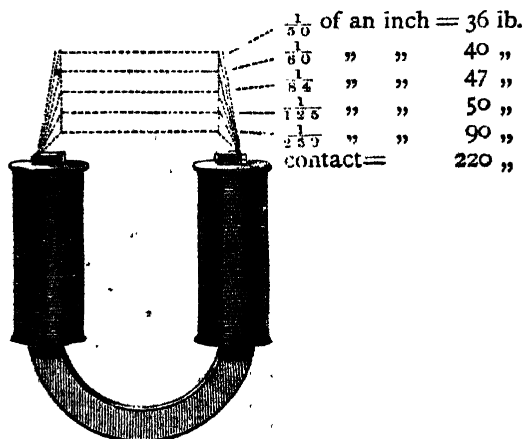


FIG. 348.

It is shown that, whilst *contact* gave a power of 220 lb., at a distance of $\frac{1}{50}$ of an inch the attractive force diminished to 36 lb.

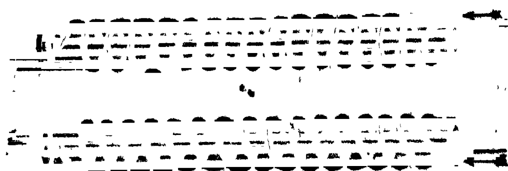


FIG. 349.—*A Dextrorsal and a Sinistrorsal Helix.*

When a wire, traversed by an electric current, is held in iron filings, they

adhere to it as long as the current passes. If the wire is coiled upwards round a glass tube from left to right, it is called a dextrorsal helix; and if coiled downwards, and in the same direction, it is termed a sinistrorsal helix.

A piece of steel placed inside such a helix, conveying the voltaic current, is soon magnetized. If the same coil is used to convey the charge from a Leyden battery of 6 ft. surface, a piece of steel is instantly magnetized. Electricians had missed this form of the experiment until Œrsted's discovery.

If a bar magnet be held so that it is horizontal, and the north pole directed to the vertical portion of the rectangular wire, so supported that whilst conveying the electric current it moves freely round in a circle (Fig. 350), it will be found

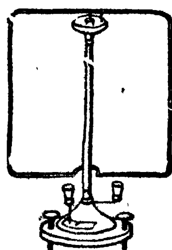


FIG. 350. — *The Rectangular Wire freely suspended on a vertical Standard.*

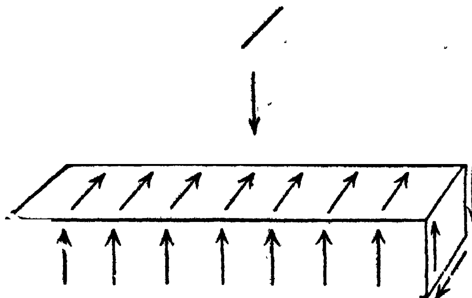


FIG. 351.

that, if the upright portion of the wire is conveying the current from below upwards, it is repelled, but attracted if the south pole is substituted; and thus, by the dexterous substitution of one pole for another in presenting the bar magnet to the rectangular wire, it may be caused to rotate.

Polarity is shown by the sides of the wire, whereas in steel magnets it is discoverable at the ends.

The same attraction and repulsion occurs if another electrified wire is brought towards the suspended rectangular wire whilst conveying the electrical current.

Fig. 351 is a good illustration of the direction of the current circulating around each section of a magnet everywhere in the same direction, viz., from top to bottom in the face that is turned towards the moving wire, and from bottom to top in that which is opposite to it. The sum of these directions amounts to a current.

A similar result is obtained when a horizontal wire is directed to a magnet suspended vertically. The magnetic currents circulating around the magnet are again shown by arrows. A magnet may, therefore, says De la Rive, be considered as formed by an association of electric currents, all circulating in the same direction around its surface, and all situated in planes parallel to each other, and perpendicular to the axis of the magnet. It is this hypothesis of Ampère of the constitution of magnets, shown in Figs. 351 and 352, and which

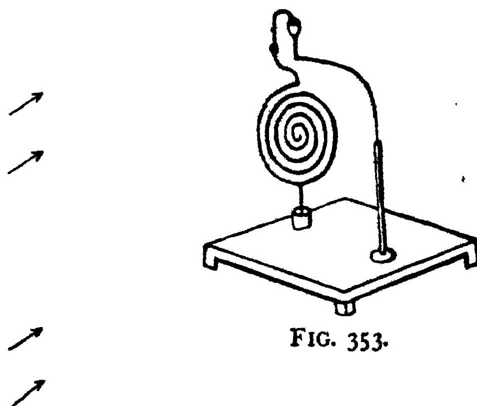


FIG. 353.

FIG. 352.—*Magnet suspended in a perpendicular line, the Current flowing horizontally.*

explains Œrsted's original experiment, and also all those that relate to the deviation. In order to confirm the hypothesis to which he had been led, of the nature of magnetism, Ampère endeavoured to arrange electric currents in the same manner as he had conceived they were naturally arranged in a magnet.

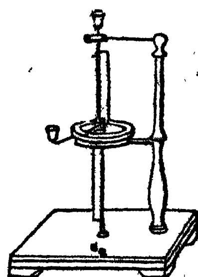


FIG. 354.—*Magnet revolving around Wire conveying the Current.*

Thus a flat spiral coil of wire (Fig. 353), nicely supported and resting on points, and perfectly mobile, takes a position perpendicular to the magnetic meridian. By reversing the experiment, and causing the wire to be fixed, and the magnet

to revolve around it (Fig. 354), further proof was obtained by Faraday of the mutual relations between magnets and wires conveying the voltaic current. In this case we have the revolution of one pole of a magnet about a vertical wire transmitting a rectilinear current. The direction of rotation is reversed each time the direction of the current is reversed.

Or the experiment may be again modified and reversed by supporting (as with the apparatus made so nicely by Messrs. Elliott) two helices or coils of copper which are made to convey the voltaic current, and rotate in opposite directions around the po'es of the horse-shoe magnet, as shown in Fig. 355.

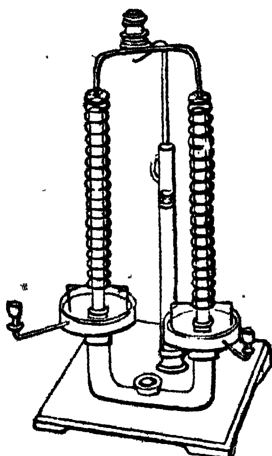


FIG. 355.—*Contrary Rotation of two helical Coiled Wires around the Poles of a Magnet.*

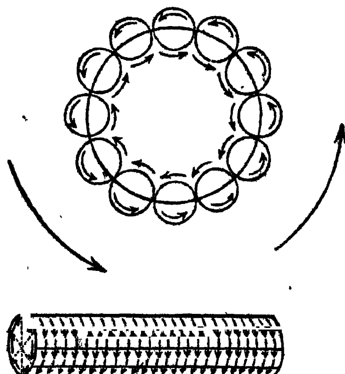


FIG. 356.

This apparatus is usually called Ritchie's Spirals. De la Rive says Ampère succeeded in overcoming all objections to his theory, and established it on such a solid basis that it is at the present time generally admitted. He set out from the principle that the electric currents to which, according to his view, magnets owe their properties are molecular, that is, that they circulate around each particle. These electric currents pre-exist in all magnetic bodies even although they have not been magnetized, only they are arranged in an irregular manner, so that they neutralize each other. Magnetization is the operation by which a common direction is impressed upon them; whence it follows that the series of the exterior portion of the molecular currents, which are all moving in the same direction, constitutes a finished current around the magnet, whilst the interior portions are neutralized by the exterior ones, moving in the contrary direction, of the following molecular stratum.

Fig. 356 represents the section of a cylinder magnet and the magnet itself. The direction impressed upon the currents by magnetization is maintained in bodies that are endued will coercitive force, and ceases in others, such as soft iron, as soon as the force that determined it ceases, because then all the molecular currents, being free to obey their mutual action, take the relative position that produces equilibrium, or the neutralization of every exterior effect.

To Faraday is due the credit of realising the idea that the mutual reaction of magnets or wires conveying electrical currents, and *vice versâ*, should produce rotation; and he was the first to cause a wire conveying a current to revolve around a magnet, and the latter to rotate about a wire through which the voltaic current is passing.

These original and philosophical experiments have been extended to larger apparatus, and various attempts have been made to use the electro-magnetic rotation successfully: Dal Negro, 1832; Professor Botto and Professor Jacobi in 1835; Mr. Thomas Davenport, of the United States, in 1837; and Mr. Taylor in 1839.

Davidson, in 1837, placed an electro-magnetic locomotive on the Edinburgh and Glasgow Railway. The carriage was 16 ft. long and 6 ft. broad, and weighed about 5 tons, with all the arrangements; but, when put in motion, a speed of only 4 miles per hour could be obtained.

Professor Page constructed an electro-magnetic engine which created much interest at the time, and he calculated that the consumption of 3 lb. of zinc per diem was equal to one horse power. Page's engine was followed by those of Talbot and Wheatstone.

Mr. Hjörth exhibited in London an engine which found many admirers. The attractive force of Hjörth's machine is thus given by Mr. Hart, from whose valuable paper the above historical details are taken:

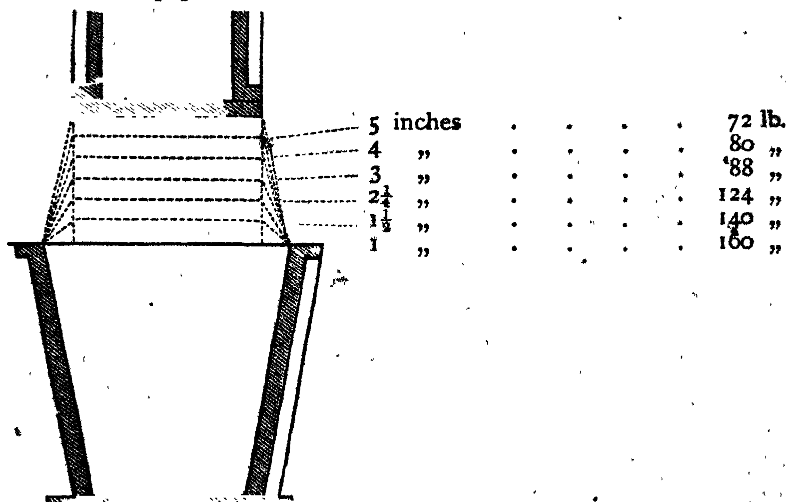


FIG. 357.—*Hjörth's Principle.*

but, like the rest, it was abandoned.

Dr. Botto states that 45 lb. of zinc consumed in a Grove's battery are sufficient to work a one-horse power electro-magnetic engine for twenty-four hours.

Mr. J. P. Joule calculates that the same result would have been obtained by the consumption of 75 lb. of zinc in a Daniell's battery. Mr. Joule and Dr. Scoresby thus sum up a series of experimental results:—"Upon the whole,

we feel ourselves justified in fixing the maximum available duty of an electro-magnetic engine, worked by a Daniell's battery, at 8c lb. raised one foot high for each grain of zinc consumed. This is about one-half of the theoretical maximum duty. In the Cornish engines doing the best duty, one grain of coal raised 143 lb. one foot high. Zinc i. worth about £35 per ton, and engine coal is worth less than £1 per ton, delivered in London. Comment upon this is unnecessary.

The fact is, an electro-magnetic engine is a very pretty toy, and can be used, like Mr. Apps's half-horse power engine (Fig. 345, p. 370), to turn a small lathe, or propel a small boat, or turn whirling tables or other apparatus on the lecture-table, *i.e.*, where the cost of zinc and acids from the battery is of no consequence. Mr. Apps furnishes the following particulars of the above named electro-magnetic engine:

"Weight 80 lb. When driven to 400 revolutions per minute by 20 cells Grove (platina 6 in. × 3 in.), a half-horse power is obtained. It will drive with equal facility in either direction, or, on reversing the current by the double commutator, the magnetic power produced is opposite to the momentum previously acquired (acting like a friction-brake); the direction of rotation is reversed, and in about three seconds the former rate of speed is acquired.

"A very important point is gained in this machine. The current being gradually broken, the spark usually produced at the breaking of the contact is avoided. Besides this great advantage, the residual magnetism is destroyed, which alone in the old machines diminished their power by at least one quarter. The machine is well adapted to drive a lathe or the screw propeller of a small boat."

MAGNETO-ELECTRICITY.

INDUCTION BY CURRENT ELECTRICITY.

It has been noticed that a current of electricity elicits magnetism, and therefore it is not surprising that the effect should be reversible; but, simple as this may appear in theory, it was a long time before Faraday succeeded in overcoming the difficulties he encountered, and was enabled to relate his success in the "Philosophical Magazine, 1832, page 125.

The extremities of a helix or large hollow bobbin of wire were connected with the galvanometer needle, care being taken that the galvanometer should not be near enough to be affected by the magnet which Faraday used.

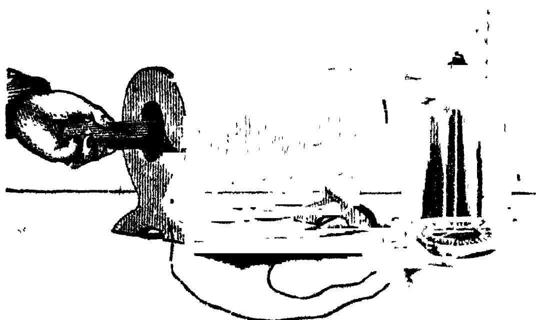


FIG. 358.—*Faraday's first Experiment.*

The movement of the bar magnet across the coils produced a current which affected the needle, and still better when, as in Fig. 358, the magnet was intruded into the axis or hollow of the bobbin or helix. Not only is the needle deflected when the magnet is insulated, but it is also moved in an opposite direction when the magnet is removed.

When two concentric helices, of course of insulated or covered wire, are arranged, the inner one being of thicker wire than the outer, and wound round an axis or core of soft iron, a very powerful secondary current is obtained in the outer coil when the inner core is magnetized. Such currents are called induced currents, and are always more powerful when soft iron forms the axis or core, because the iron, in acquiring or losing magnetism, produces a secondary current which occurs in the same direction as that induced by the inner coil or helix.

Here, then, is a distinct excitation or elimination of electricity by magnetism alone, and is called magnetic electric induction to distinguish it from volta-electric induction, also investigated by Faraday, and brought before the Royal

Society in 1831. In the latter experiments, two great coils of wires were wound together, metallic contact, of course, being prevented. One coil was connected with the galvanometer, and the other with the voltaic battery. The induced electricity in the second coil was suddenly produced like a wave, presenting a marked difference to the magneto-electric induction, which was much slower in its production. Here, then, are two modes of induction:

1. VOLTA-ELECTRIC INDUCTION;
2. MAGNETO-ELECTRIC INDUCTION.

The magneto-electric induction has been applied to the production of currents of electricity by Pixii—the first in Paris, 1832, followed by Saxton and E. M. Clarke.

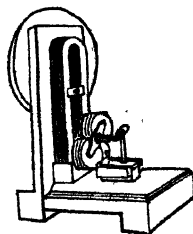


FIG. 359.

Such instruments, in which a powerful compound-magnet, having rotating in front of its poles an armature or bobbin of fine wire (which may be varied to produce either quantity or intensity effects), elicits a current that can be made to illustrate physiological, mechanical, chemical, and ordinary electrical effects, are so fully described in every book on electricity that the writer prefers to pass to newer and more perfect arrangements.

Magneto-electricity was applied and exhibited by Mr. Holmes in the Great Exhibition of 1862, and obtained from a machine of novel construction. At the same Exhibition, and also in Paris, 1867, the writer saw Nollet's machine as improved by Mr. van Malderen, who took great pains to show the writer the construction of his magneto-electric machine for light-giving purposes; and it was understood that, at a cost of £300, one of these machines, turned by a steam-engine, might supply the Polytechnic with the electric light at any time it was set in motion. The current passed to a Serrin's lamp, and certainly produced a most brilliant light.

In the article on the Telegraph, it will be noticed that Sir Charles Wheatstone uses a magneto-electrical machine of improved construction, instead of the voltaic battery. Wheatstone's exploder for military purposes generates its electricity in the same manner. There are many other modifications of induced currents, such as the experiments of Faraday, "On the Induction of a Current on itself," read before the Royal Society, 1835; and Dr. Henry's (College of New Jersey, Princeton) experiments (described in 1833) with flat coils of insulated copper ribbon and helices of fine covered copper wire, by which induced currents of the third, fourth, and fifth order could be obtained, by alternately arranging the insulated copper ribbons and the helices of fine wire.

In the "Proceedings of the Royal Society," No. 90, 1867, Sir Charles Wheatstone describes a most interesting series of experiments "On the Augmentation of the Power of a Magnet by the reaction thereon of Currents induced by the Magnet itself," as follows:

"The magneto-electric machines which have been hitherto described are actuated either by a permanent magnet or by an electro-magnet deriving its power from a rheomotor placed in the circuit of its coil. In the present note, I intend to show that an electro-magnet, if it possess at the commencement the slightest polarity, may become a powerful magnet by the gradually augmenting currents which itself originates.

"The following is a description of the form and dimensions of the electro-magnet I have employed. The construction, it will be seen, is the same as that of the electro-magnetic part of Mr. Wilde's machine.

"The core of the electro-magnet is formed of a plate of soft iron, 15 in. in length and $\frac{1}{2}$ an inch in breadth, bent at the middle of its length into a horse-shoe form. Round it is coiled, in the direction of its breadth, 640 ft. of insulated copper wire $\frac{1}{12}$ of an inch in diameter. The armature, which is according to Siemens's ingenious construction, consists of a rotating cylinder of soft iron, $8\frac{1}{2}$ in. in length, grooved at two opposite sides so as to allow the wire to be coiled upon it longitudinally; the length of the wire thus coiled is 80 ft., and its diameter is the same as that of the electro-magnet coil.

"When this electro-magnet is excited by any rheomotor the current from which is in a constant direction, during the rotation of the armature, currents are generated in its cell during each semi-revolution, which are alternately in opposite directions; these alternate currents may be transmitted unchanged to another part of the circuit, or by means of a rheotrope be converted to the same direction.

"If now, while the circuit of the armature remains completed, the rheomotor be removed from the electro-magnet, on causing the armature to revolve, however rapidly, it will be found by the interposition of a galvanometer, or any other test, that but very slight effects take place. Though these effects become stronger in proportion to the residual magnetism left in the electro-magnet from the previous action of a current, they never attain any considerable amount.

"But if the wires of the two circuits be so joined as to form a single circuit, in which the currents generated by the armature, after being changed to the same direction, act so as to increase the existing polarity of the electro-magnet, very different results will be obtained. The force required to move the machine will be far greater, showing a great increase of magnetic power in the horse-shoe; and the existence of an energetic current in the wire is shown by its action on a galvanometer, by its heating 4 in. of platinum wire ·0067 in diameter, by its making a powerful electro-magnet, by its decomposing water, and by other tests.

"The explanation of these effects is as follows:—The electro-magnet always retains a slight residual magnetism, and is therefore in the condition of a weak permanent magnet; the motion of the armature occasions feeble currents in alternate directions in the coils thereof, which, after being reduced to the same direction, pass into the coil of the electro-magnet in such manner as to increase the magnetism of the iron core; the magnet, having thus received an accession of strength, produces in its turn more energetic currents in the coil of the armature; and these alternate actions continue until a maximum is attained, depending on the rapidity of the motion and the capacity of the electro-magnet.

"If the two coils be connected in such manner that the rectified current from the coil of the armature passes into the coil of the electro-magnet in the direction which would impart a contrary magnetism to the iron core, no current is produced, and consequently there is no augmentation of magnetism.

"It is easy to prove that the residual magnetism of the electro-magnet is the determining cause of these powerful effects. For this purpose it is sufficient to pass a current from a voltaic battery, a magneto-electric machine, or any other rheomotor, into the coil of the electro-magnet in either direction,

and it will invariably be found that the direction of the current, however powerful it may eventually become, is in accordance with the polarity of the magnetism impressed on the iron core.

"If, instead of the currents in the coil of the rotating armature being reduced to the same uniform direction, they retain their alternations, no effects, or at most very small differential ones, are produced, as no accumulation of magnetism then takes place.

"I will now call attention to the fact that stronger effects are produced at the first moment of completing the combined circuit than afterwards. The machine having been put in motion, at the first moment of completing the circuit 4 in. of platina wire were made red hot; but immediately afterwards the glow disappeared, and only about one inch of the wire could be permanently kept at a red heat. This diminution of effect was accompanied by a great increase of the resistance of the machine. The cause of the momentary strong effect was, that the machine from its acquired momentum continued its motion for a few seconds, though it required a stronger force than could be applied to maintain that motion. Each time the circuit is broken and recompleted, the same effect recurs.

"On bringing the primary coil of an inductorium (Ruhmkorff's coil) into the circuit formed by connecting the coils of the electro-magnet and rotating armature, no spark occurs in the secondary coil. On account of the great resistance of the circuit, which now also includes the primary coil of the inductorium, the current is not in sufficient quantity to produce any noticeable inductive effect.

"A very remarkable increase of all the effects, accompanied by a diminution in the resistance of the machine, is observed when a cross wire is placed so as to divert a great portion of the current from the electro-magnet. The four inches of platinum wire, instead of flashing into redness and then disappearing, remains permanently ignited. The inductorium, which before gave no spark, now gave one a quarter of an inch in length; water was more abundantly decomposed; and all the other effects were similarly increased.

"I account for this augmentation of the effects in the following way:

"Though so much of the current is diverted from the electro-magnet by the cross wire, the magnetic effect still continues to accumulate, though not to so high a degree; but the current generated by the armature, passing through the short circuit formed by the armature branch and cross wire, experiences a far less resistance than if it had passed through the armature and electric-magnet branches; and though the electromotive force is less, the resistance having been rendered less in a much greater proportion, the resultant effect is greater.

"I must observe that a certain amount of resistance in the cross wire is necessary to produce the maximum effect. If the resistance be too small, the electro-magnet does not acquire sufficient magnetism; and if it be too great, though the magnetism becomes stronger, the increase of resistance more than counterbalances its effect.

"But the effects already described are far inferior to those obtained by causing them to take place in the cross wire itself. With the same application of force, 7 in. of platinum wire were made red hot, and sparks were elicited in the inductorium 2½ in. in length.

"The force of two men was employed in these, as well as in the other experiments. When the interrupter of the primary coil was fixed, the machine

was much easier to move than when it acted. For when the interrupter acted, as each moment of interruption the cross wire being, as it were, removed, the whole of the current passed through the electro-magnet, and consequently a greater amount of magnetic energy was excited, while in the intervals during which the cross wire was complete the current passed mainly through the primary coil.

"The effects are much less influenced by a resistance in the electro-magnet branch than in either of the other branches.

"To reduce the length of the spark in the inductorium (the primary coil of which was placed in the cross wire) to $\frac{3}{4}$ of an inch, it required the resistance of $5\frac{1}{4}$ in. of the fine platinum wire in the cross wire, 5 in. in the armature branch, and 4 ft. in the electro-magnet branch.

"When there was no extra-resistance in either of the branches, the length of the cross wire being only about a few feet, the intensity of the current in the electro-magnet branch, compared with that in the cross wire, was as 1 : 60; and when the resistance of the primary coil of the inductorium was interposed in the cross wire, the relative intensities were as 1 : 42.

"In conclusion, I will mention that there is an evident analogy between the augmentation of the power of a weak magnet by means of an inductive action produced by itself, and that accumulation of power shown in the static electric machines of Holtz and others, which have recently excited considerable attention, in which a very small quantity of electricity directly excited is, by a series of inductive actions, augmented so as to equal, and even exceed, the effects of the most powerful machines of the ordinary construction."

Mr. Wilde's machine has been fully described in all the illustrated scientific papers, such as "The Engineer" and "The Mechanic's Magazine." The writer, therefore, proposes to give drawings of Mr. Ladd's improved magneto-electric machine, which he thus describes in the "Transactions of the Royal Society," No. 91, 1867:

"In June, 1864, I received from Mr. Wilde a small magneto-electric machine, consisting of a Siemens's armature and six magnets. This I endeavoured to improve upon, my object being to get a cheap machine for blasting with Abel's fusees. This was done by making one of circular magnets, and a Siemens's armature revolving directly between the poles, the armature forming part of the circle; with this I could send a very considerable power into an electro-magnet, &c. It was then suggested to me, by my assistant, that if the armature had two wires instead of one, the current from one being sent through a wire surrounding the magnets, their power would be augmented, and a considerable current might be obtained from the other wire available for external work; or there might be two armatures—one to exalt the power of the magnets, and the other made available for blasting or other purposes. Want of time prevented me carrying this out until now; but since the interesting papers of C. W. Siemens, F.R.S., and Professor Wheatstone, F.R.S., were read last month, I have carried out the idea as follows:—Two bars of soft iron, measuring $7\frac{1}{2}$ in. × $2\frac{1}{2}$ in. × $\frac{1}{2}$ in., are each wound, round the centre portions, with about thirty yards of No. 10 copper wire, and shoes of soft iron are so attached at each end, that when the bars are placed one above the other there will be a space left between the opposite shoes, in which a Siemens's armature can rotate: on each of the armatures is wound about ten yards of No. 14 copper wire, cotton-covered. The current generated in one of the armatures is always in connexion with the electro-magnets; and the current from the second arma-

ture, being perfectly free, can be used for any purpose for which it may be required. The machine is altogether rudely constructed, and is only intended to illustrate the principle; but with this small machine three inches of platinum wire ·01 can be made incandescent."

Mr. Ladd now calls his improved machine, which it is hoped may be permanently erected some day at the Polytechnic as a convenient source of electricity for all purposes, the "Dynamo-Magnetic Machine" (Fig. 360).

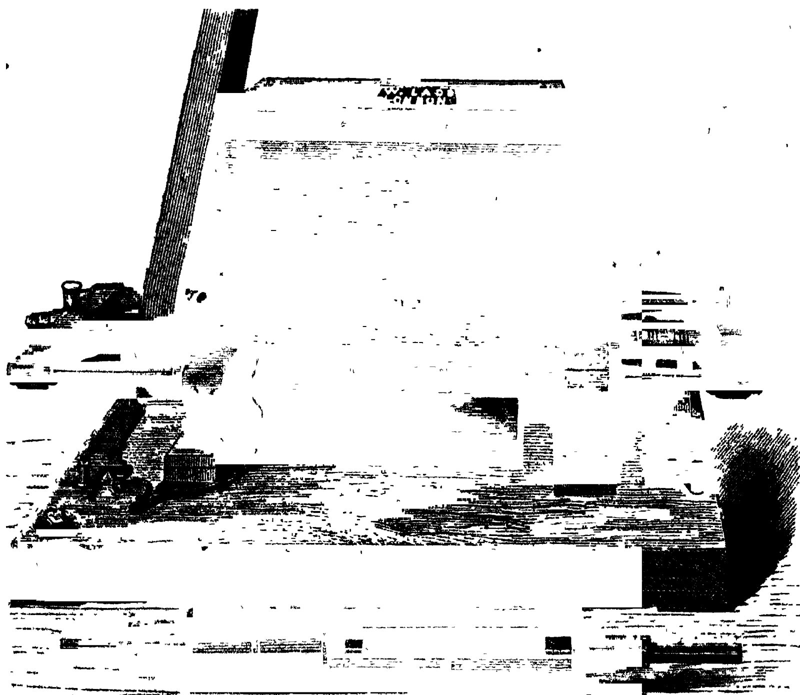


FIG. 360.

This machine was awarded a silver medal at the Paris Exhibition, 1867. Another form of the apparatus (Fig. 361), also constructed by Mr. Ladd, is that in which the two armatures are combined in one, and the coils are wound at right angles to each other.

The results obtained are simply regulated by the amount of mechanical force used to rotate the armatures; and thus indirectly coal, used as a means of exciting electricity, is made to generate steam, which produces force in the steam engine, and this ultimately turns the dynamo-magnetic machine; and thus *indirectly* coal generates an electric current, by which the electric light is obtained.

A convenient little magneto-electrical machine is made by Mr. Browning, for the purpose of giving shocks and for medical use. (Fig. 362.)

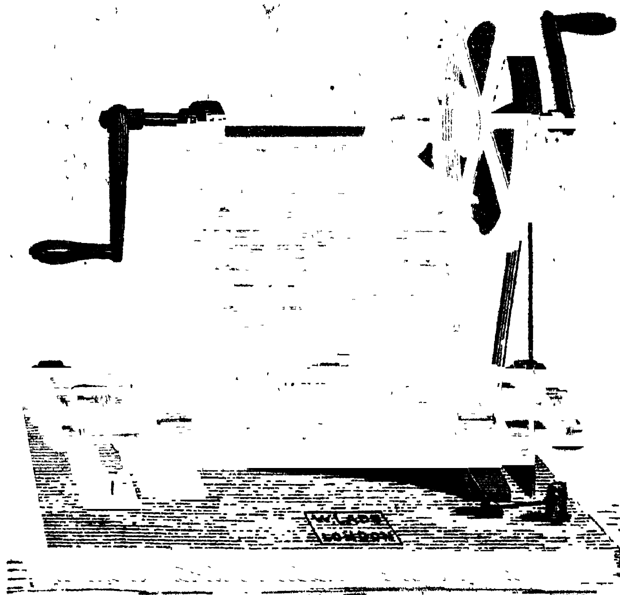


FIG. 361.

Directions for using the Instrument.—Take the hollow conductors A B off from the large studs on which they are placed; uncoil their metallic cords which are wound upon them, and insert the pins which are attached to the ends of these cords into the small holes which will be found in two upright brass studs at the back of the stand of the machine, marked C D in the diagram; then upon holding the hollow conductors, one in each hand, and turning the handle of the machine quickly, a strong electrical current will be felt.

A horizontal stud in front of the machine, projecting beyond the frame, serves to move an iron feeder before the ends of the large circular magnet. By shifting this feeder, the strength of the current given out by the machine can be regulated within any desirable limit. When the feeder is lifted up in front of the magnet, the current will be very feeble; when it is withdrawn quite below the magnet, it will be very intense.

Two brass springs project from the brass studs C D; these springs should rest on the edge of a small wheel of ebonite and brass, known as a commutator. It sometimes happens that, from rough usage in carriage, these springs are bent, so that they no longer touch the edge of the wheel; in this case the current becomes greatly weakened, or altogether ceases; but the machine can be easily set right by carefully bending down the springs so that they again rest upon the edge of the wheel.

We now come to the last of the induction machines, sometimes called the induction coil, the inductorium, &c. In 1851, M. Ruhmkorff, a most clever instrument maker in Paris, made a coil which produced in the scientific world

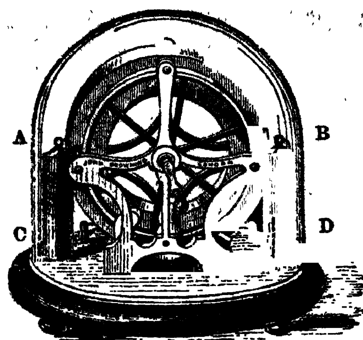


FIG. 362.—*Browning's Magneto-Electrical Machine.*

of Paris and London a profound sensation of surprise and delight at the beautiful light-effects obtainable.

Mr. Hearder, of Plymouth, and Mr. Bentley subsequently made coils of great power; but to Mr. Ladd is due the merit of constructing a serviceable apparatus which would always produce the most reliable results. A very large coil, having a secondary coil of seven miles of wire, has long been used at the Polytechnic. It consists of the usual primary coil, wound round a faggot of iron wires; around this is the secondary coil, of the required number of miles in length. The condenser, composed of alternate sheets of tinfoil and well dried and varnished paper, is placed under the coil, and, by making and breaking contact with the primary by a convenient "contact-breaker," an enormous current is induced in the secondary, which produces the most brilliant results.



FIG. 363.—*Plücker's Tube.*

A Leyden jar or Leyden plate may be incessantly charged and discharged with a continuous roar. Paper is immediately set on fire when held between the poles. Tubes of glass are filled with various gases or liquids, or rather not filled according to the ordinary acceptation of the term, because they are *vaçua*, the last gas which has been permitted to enter the tube alone representing the attenuated atmosphere through which the electric current passes.

The reader is referred to Dr. Noad's little book, entitled "The Inductorium," and published by Churchill for Mr. Ladd, for all the minute details connected with the primary coil, the secondary, the condenser, and the thousand-and-

one experiments which, like the "Arabian Nights' Entertainments," crowd upon the student, but which may all be performed with the apparatus described.

Amongst the most interesting experiments, that of Plücker deserves especial notice.

"Two aluminium rings are hermetically sealed into a glass tube, 4 or 5 in. long and about $1\frac{1}{2}$ in. in diameter; the air in the tube is then exhausted as perfectly as possible. On passing the discharge from the induction coil between the two rings, the tube becomes filled with a beautiful pale blue light.



FIG. 364.—*Plücker's Tube with Aluminium Wires.*

"If the small ring be made negative, and the tube placed between the poles of an electro-magnet, the moment the latter is excited the light arranges itself in the form of a broad arc between the rings.

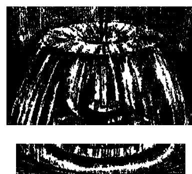


FIG. 365.—*Gassiot's Cascade,*

The current passing into and out of a glass vessel placed in a vacuum.

"On rendering the electro-magnet passive, the arc disappears, the light in the tube re-assuming its different character; but, on re-exciting the magnet,

the arc re-appears. If, instead of two rings, the terminals in the tube are two aluminium wires, as shown in Fig. 364, the long wire being made positive and the short wire negative, the arc produced is very broad and brilliant."

It must be apparent from the preceding figures that the stratification noticeable in all experiments of this type is a special object of interest, to which M. Gassiot, the generous and large-hearted friend of science, has paid particular attention.

Speaking of Geissler's (of Bonn) tubes,—one of the prettiest arrangements the writer has seen is that of Mr. Apps, and shown in the next figure.

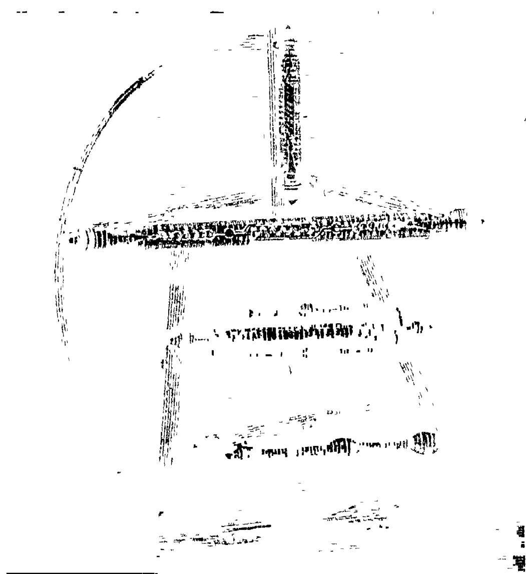


FIG. 366.—*Front View of Geissler's Tubes, arranged on a disc of blackened Mahogany.*

The back view exhibits the use of the electro-magnetic engine for rotating or reversing the disc. (Fig. 367.)

The electro-magnetic engine, in a convenient and handsome form, well adapted to rotate the vacuum tubes, is attached to the black polished disc, and arranged so as to turn in either direction: the speed can be easily regulated. The discharge from the coil passes through the entire series of tubes.

Amongst the remarkable effects produced by the induction coil, there are none more interesting than the generation of ozone by the "ozone tube," which is thus described by Dr. Noad, and made by Mr. Ladd. (Fig. 368.)

It consists of a glass tube, about the size of an ordinary test tube, coated with tinfoil or, still better, silvered, and enclosed in an outer tube lined outside with tinfoil. The two tubes are sealed together at the neck of the outer

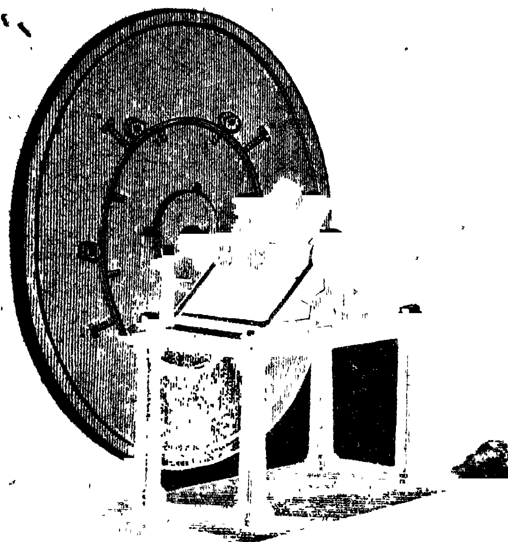


FIG. 367.

one, and so adjusted that the space between them shall be as narrow as possible.

At the projecting end of the inner tube is a brass button, which is connected by a spring with one of the binding-screws on the frame of the apparatus, which screw is to be connected with one of the terminals of the secondary coil of an inductorium, and the other with another binding-screw in metallic communication with the coating of the exterior tube.

The apparatus is, in fact, a sort of slit Leyden jar; and air or oxygen, admitted through the lateral tube, becomes during its passage through the apparatus powerfully ozonized.

The air may be driven through by means of a bladder or india-rubber bag, or drawn through with an aspirator.

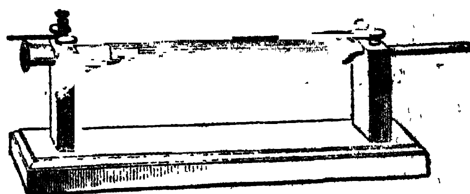


FIG. 368.—*The Ozone-Tube.*

Mr. Edward Beanes, who has already done so much in improving certain processes required in the manufacture of sugar, has patented the application of apparatus for generating ozone and bleaching syrup, and, although there appears to be some difficulty in obtaining enough ozone for this purpose, the experiments hitherto tried are very promising.

The writer abstains from saying anything about a new gigantic coil, building for the Polytechnic by Mr. Apps. Like David with his armour, he has not proved it: had he done so, this article would have contained an account of the Mammoth Induction Coil.

"On re
the tube re-

THERMO-ELECTRICITY.

Electricity produces magnetism, heat, light, mechanical and chemical effects. It is not opposed to the harmony of created forces that heat should produce electricity.

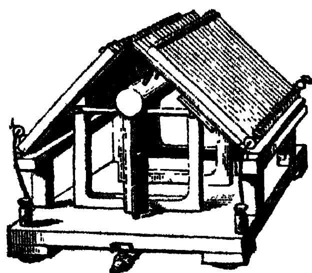


FIG. 369.—*Marcus's Thermo-Electric Battery, made by Mr. Ladd.*

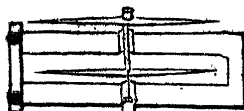


FIG. 370.

The above battery (Fig. 369) consists of thirty-six elements; the negative bars, which are 6 in. long, being composed of 12 parts of antimony, 5 of zinc, and 1 of bismuth; and the positive bars, which are 7 in. long, of copper 10 parts, zinc 6 parts, and nickel 6 parts. The bars are ranged on a frame in the slanting position shown in the figure, and were facetiously referred to by a writer in "Punch" as a "chestnut roaster," the positive bar of the first pair being metallically connected with the negative of the second, and the two extreme bars connected with binding-screws which form the terminals of the battery. The upper ends of the bars are heated by a series of Bunsen's burners, the flames of which can be easily regulated.

This battery at the Polytechnic, under the charge of Mr. J. L. King, decomposed water, of course very feebly; it gave small sparks between iron points without the assistance of a coil, and enabled an electro-magnet to support a considerable weight, and, when connected with an induction coil, gave sparks which were very marked in their character and length.

We have now to ask how this apparatus, in which heat takes the place of friction, chemical action, or magnetism, elicits electric force.

Seebeck's apparatus, a rectangular figure, made of bismuth and antimony, with an astatic magnetic needle supported inside, well exhibits the thermo-electric action; and, directly one of the angles is gently heated by a spirit flame, the needle, like that of the galvanometer with the voltaic circuit, is deflected. (Fig. 370.)

Pouillet's thermo-electric apparatus (made by Elliott), and already figured in Wheatstone's paper on the Rheostat (p. 333), consisting of a short cylindrical bar of bismuth, bent twice at right angles, with soldered copper wires attached to the ends, communicating with an ingenious contrivance on the stand for

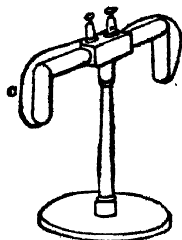


FIG. 371.—*Pouillet Thermo-Electric Circle.*

completing the electric circuit in any direction, is another and most perfect arrangement for showing currents of electricity obtainable by the exciter, "heat." (Fig. 371.)

On the second or third page of this work, in the article on Light, Melloni's small and compact composite "thermo-electric pile" is specially alluded to.

When the writer was a student, thirty years ago, he well remembers trying experiments with this beautiful contrivance for showing minute disturbances of heat; and, at that time, it had the reputation of being delicate enough to show the heat of the body of a "fly or a blue-bottle." Exaggeration apart, its

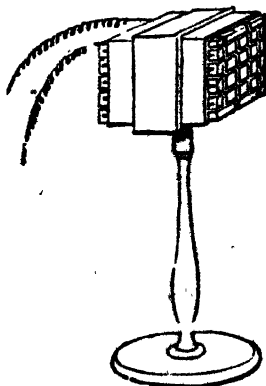


FIG. 372.—*Melloni's Thermo-Electric Pile or Battery.*

power to show the slightest heat-wave disturbance has never been equalled by any other apparatus. It consists of a series of pairs of very slender bars of antimony and bismuth soldered alternately together, and arranged parallel side by side, so that all the soldered pairs are at one end, and all the solders not pairs at the other. This apparatus, mounted in a brass tube and placed on a stand, is now the special attendant at all lectures in which the dynamical theory of heat is taught. (Fig. 372.)

The late Mr. Francis Watkins, the predecessor of the Messrs. Elliott, paid particular attention to this subject, and constructed a "Thermo-Electric Combinator." Eighteen pairs of bismuth and antimony, united alternately by

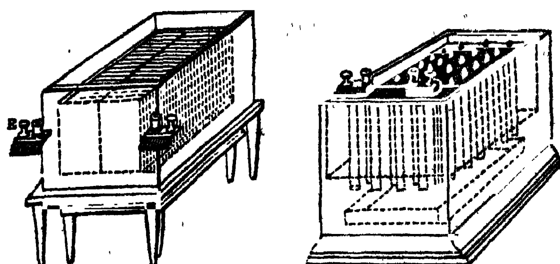


FIG. 373.—*Van der Voort's Thermo-Electric Battery.*

solder top and bottom, and fixed in a mahogany box by plaster of paris, leave the two extremities to be acted upon, the one by heat and heated iron or boiling oil, and the other by cold—some ice or a freezing mixture. All the common effects of an electric current, such as the spark, &c., can be shown with this contrivance.

Thus the corelation of forces is complete, and Light, Heat, Electricity, and Magnetism resolve themselves into each other, and represent probably a series of waves, every one of which is different from the other in the phases of its vibrations and resultant form.



FIG. 374.—*Portrait and Autograph of Sir Charles Wheatstone.*

WHEATSTONE'S TELEGRAPHS.

The limits of this article will not permit of any lengthened history of all the clever inventions either proposed or carried out by the various scientific men who have contributed to our knowledge of the science of telegraphy.

Whatever amount of credit may be accorded to others, there can be but one opinion respecting the merits of a living philosopher, whose portrait graces the head of this chapter. Foreigners are usually very frank and honest in their expression of the amount of merit due to their contemporaries in other

countries. The jury of the French Exhibition of 1855 thus report upon Wheatstone:

"La transmission de l'électricité entre les pays séparés par la mer n'a pu s'effectuer qu'au moyen de cables particuliers unissant entre elles les stations télégraphiques. Mais combien de travaux n'a-t-il pas fallu pour atteindre ce but; et même maintenant que la question est résolue, on ne peut sans admiration penser que la transmission des dépêches télégraphiques est aussi facile à l'aide des cables sous-marins qu'au moyen des fils isolés et tendus dans l'air. C'est par l'emploi de ces cables que l'on a pu mettre en relation télégraphique la France et l'Angleterre, la Crimée et les provinces Danubiennes, les pays enfin dans lesquels ces principes ont été appliqués, et peut-être bientôt l'Europe et l'Amérique. Le Jury a voté une mention très-honorable pour M. Wheatstone (Royaume Uni), membre du Jury de la IX^e classe, pour avoir conçu l'idée première et pour avoir proposé, en 1840, un moyen de résoudre la question; il accorde la même distinction à M. Brett (Royaume Uni), sous la direction duquel a été placé un conducteur au travers de la Manche, entre Douvres et Calais, et qui a montré ainsi que le succès était possible. Le Jury décerne également une mention très-honorable à M. Crampton (Royaume Uni), membre du Jury de la V^e classe, auquel revient l'honneur d'avoir réalisé cette immense application, en unissant définitivement, en 1851, par un cable sous-marin, la France et l'Angleterre."

Another very distinguished foreigner, A. De la Rive, thus speaks of Wheatstone in his "Treatise on Electricity:"

"The philosopher who was the first to contribute by his labours, as ingenious as they were persevering, in giving to electric telegraphy the practical character that it now possesses is, without any doubt, Mr. Wheatstone. This illustrious philosopher was led to this beautiful result by the researches that he had made in 1834 upon the velocity of electricity—researches in which he had employed insulated wires of several miles in length, and which had demonstrated to him the possibility of making voltaic and magneto-electric currents to pass through circuits of this length."

The following is the order of the inventions made by Sir Charles Wheatstone:

The 5-needle telegraph, 1837.
The alphabet-dial telegraph, 1840.
The type-printing telegraph, 1841.
The new magnetic alphabetic-dial telegraph, 1858-60.
The fast-speed automatic telegraph, 1858—1867.

Sir Charles Wheatstone, in addition to the other honours he has lately received, has just been elected to replace Faraday as one of the twelve corresponding members of the "Società Italiana delle Scienze, detta dei XL.," and has also received their first gold medal, instituted during the present year by the late Minister of Public Instruction, Signor Matteucci, to honour the most important discoveries in physical science.

The president, in his address, says:

"I will not here pass in review the various memoirs in physics which you have published in the 'Philosophical Transactions,' since all carry the impression of the inventive genius which ever distinguishes all that you have done. I cannot, however, refrain from calling to mind that to you we owe the discovery of the method, as ingenious as it is original, for measuring the velocity of electric currents and the duration of the spark.

"The applications of the principle of the rotating mirror are so important and so various that this discovery must be considered as one of those which have most contributed in these latter times to the progress of experimental physics.

"Not less ingenious was the invention of the stereoscope and of the modes by which binocular vision is effected, which enable us to obtain the perception of relief from the simultaneous observation of two plane images.

"Also the memoir on the measure of electric currents, and on all the questions which relate thereto and to the laws of Ohm, has powerfully contributed to spread among physicists the knowledge of those facts and the mode of measuring them with an accuracy and simplicity which before we did not possess.

"All physicists know how many researches have since been undertaken with your rheostat (see p. 333) and with the so-called Wheatstone's bridge, and how usefully these instruments have been applied to the measure of electric currents, of the resistance of circuits, and of electro-motive forces.

"And here it would be impossible to leave out of view that to you we principally owe the practical invention and the true realization of the electric telegraph.

"Finally, I would call to mind your recent researches on the augmentation of the force of a magnet by the reaction which its own induced currents exert upon it.

"All these great acquisitions, procured by you, to physical science render you well worthy of this distinction from the Italian Society of Sciences.

"Preserve yourself in health and activity, and your country and all your admirers and friends are certain to find, in the discoveries still to be added while you continue to work, some compensation for that immense and irreparable loss which natural philosophy has received by the death of Faraday."

In addition to the memoirs by Sir Charles Wheatstone, alluded to by Signor Matteucci, the following may be specially noticed:

"On the Acoustic Figures of Vibrating Surfaces," published in the "Philosophical Transactions" for 1832. In this memoir, which gained for Sir Charles his admission into the Royal Society, the author gave for the first time the laws of formation of the varied and beautiful figures discovered by Chladni. Attention has recently been revived to this subject by König and others on the Continent.

"On the Transmission of Sound through Solid Conductors" ("Journal of the Royal Institution," 1828). This memoir describes the means discovered by the author of transmitting musical performances to distant places.

"On the Prismatic Analysis of Electric Light" (British Association, 1832). By these experiments Sir Charles proved for the first time that the spectrum of the electric spark from different metals presented each a definite series of lines differing in colour and position from each other, and that these appearances afforded the means of distinguishing the smallest fragment of one metal from that of another. This investigation was one of the earliest starting-points of an entire new branch of physical science, in which there are now many distinguished workers.

"On the Polar Clock" (British Association, 1849). This is an optical instrument which indicates the time by means of the changes in the plane of polarization of the blue light of the sky in the direction of the pole. It is founded on the discoveries of Arago and Quetelet; and Arago states that

"l'honneur de la construction de l'horloge polaire, je la reconnais avec empressement et sans réserve, revient exclusivement à M. Wheatstone."

It would carry us beyond our limits to enumerate the various inventions relating to the electric telegraph and other applications of electricity which have emanated from Sir Charles. We will mention two only.

We owe to him, in addition to his former inventions relating to the electric telegraph, the alphabetical-dial telegraph, working without any clockwork power, and in which a magneto-electric machine supplies the place of a voltaic battery. These instruments were first introduced on the Paris and Versailles Railway in 1846, and, with the improvements which the inventor has since made, have been employed to a great extent throughout the kingdom by the Universal Private Telegraph Company in furnishing telegraphic communication between public offices and private establishments, to which purposes, from their facility of manipulation and constancy of action, they are admirably adapted.

A more recent invention is his fast-speed telegraph, in which the messages, previously prepared on strips of paper by manipulations as easy as those for sending an ordinary message, are, by passing through a very small machine constructed on somewhat the principle of a Jacquard loom, made to print the messages at the remote station in the ordinary telegraphic characters, with a rapidity and distinctness unattainable by the hand of an operator. The invention of these instruments dates from 1858; but they have only, with recent improvements, been practically introduced, by the Electric Telegraph Company, during the last year. Since June last these instruments have been in constant action for the ordinary business of the establishment between London and Newcastle, printing from sixty to a hundred and ten words per minute. The result has been so successful that the company have just resolved to adopt them on other leading lines of communication.

In the report of the Paris Exhibition of 1855, honourable mention was awarded to Sir Charles, he being *hors de concours*, for having been the first to conceive the idea, and for having proposed, in 1840, a means of resolving the question, of a submarine telegraph between Dover and Calais.

It may be mentioned in reference to an eminent philosopher, Sir David Brewster (whose loss we have had to deplore), that one of the last acts of his life was to nominate Wheatstone for election as an honorary member of the Royal Society of Edinburgh, thus falsifying the couplet of Dryden, who says,

"Forgiveness to the injured does belong;
But they ne'er pardon who have done the wrong."

In 1868 Wheatstone received the honour of knighthood at the hands of his gracious sovereign, and this same year of grace the Royal Society have awarded to him their highest distinction, viz., the Copley medal.

"This is the state of man: to-day he puts forth
The tender leaves of hope; to-morrow, blossoms
And bears his blushing honours thick upon him."

In concluding this brief notice of the laborious and useful life of Wheatstone, we may, in common with all his friends and admirers, be permitted to hope that he may pass the evening of his days in peace and in the enjoyment of health, and that he will give to the world, in the calmness of matured age, a monograph of the "Labours of his Life."

In every book devoted to the consideration of electric telegraph instruments

we find illustrations and descriptions of Cooke and Wheatstone's earlier inventions of the single and double needle telegraph. We will, therefore, commence at the year 1840, when he constructed the alphabet-dial telegraph, which the writer has always found to be one of the best forms for teaching and demonstrating the broad principles upon which motion is developed by a current thrown alternately from one electro-magnet to another. Such is the construction of the telegraph, the dial of which is shown at Fig. 375.

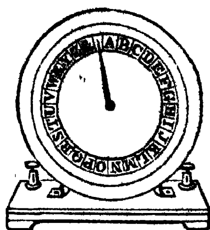


FIG. 375.—*Wheatstone's first Alphabet-Dial Telegraph* (1840).

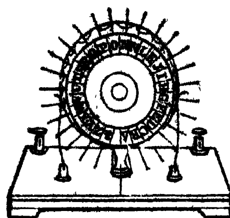


FIG. 376.—*Wheatstone's Communicator* (1840).

It consists of a circular dial, on which the letters of the alphabet are painted in black letters on a white ground. The mechanism is very simple. Two electro-magnets, with feeders and long arms, strike alternately the pallets; these take up at each blow one tooth of a wheel or escapement, and every time a tooth is taken up the hand on the dial moves forward one letter. To make the letters on the dial coincide with the letters of the sender of the message, another instrument is required, called the "communicator." (Fig. 376.)

This consists of a wheel, upon the circumference of which are thirty alternations of brass and ivory corresponding to the letters of the alphabet, &c., with which also this instrument is provided. There are two springs, one on each side, which communicate alternately with the communicator and through that to the battery and wires of the dial telegraph. When the communicator is turned round one letter, the hand or the dial moves one letter; and, if the instruments are very carefully made, they answer remarkably well.

Wheatstone, however, found that they sometimes missed a tooth in the escapement, and, of course, one letter being gone, the message afterwards might be very chaotic, particularly when a number of words in rapid succession had to be forwarded. This system was, however, at the time adopted on some of the continental lines.

Passing by the type-printing telegraph of 1841, we now come to the new magnetic alphabetic-dial telegraph of 1858 and 1860.

The reader will be able to understand the construction better by reading and examining the annexed description and diagrams than if a minute description of the above instrument (Fig. 377) were given at once. It is, perhaps, unnecessary to remark that these instruments are in daily use by the Universal Private Telegraph Company.

Instructions for connecting-up the Instruments.—The instruments (communicator, indicator, and alarum) at each station should first be placed in short circuit in the following manner (Fig. 378):

Place short wires upon the two upper terminals, *a b*, at the back of the indi-

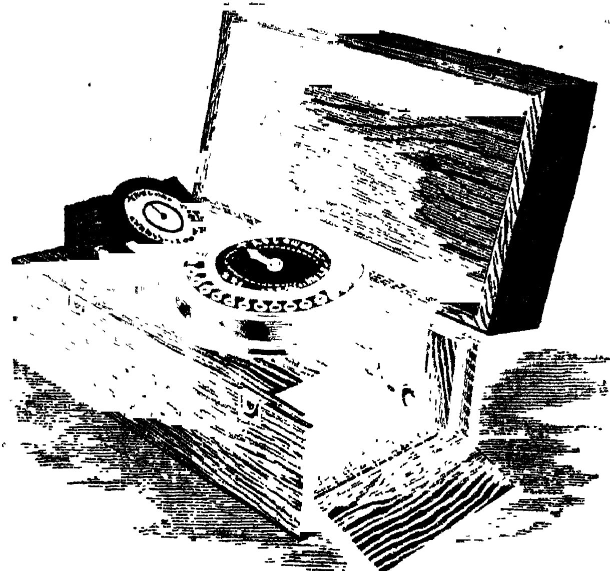


FIG. 377.—*Wheatstone's new Magnetic Alphabetic-Dial Telegraph.*

cator, and connect them with *c* and *d* respectively, the switch, *x*, being turned to point to the letter, T—Telegraph. The handle, *z*, of the communicator is then to be turned steadily at a rate of about a hundred and twenty revolutions per minute, and the index or pointer passed from + to + on the dial by

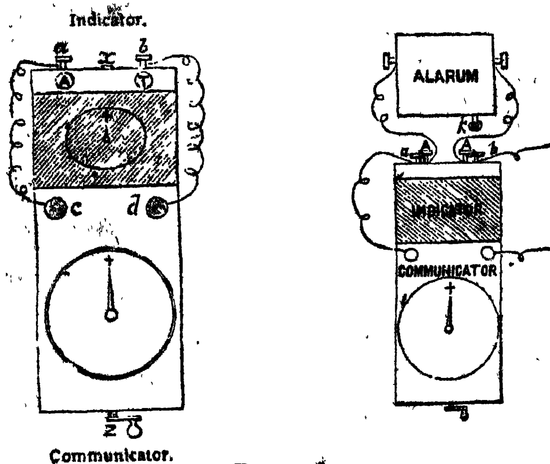


FIG. 378.

depressing the finger-key opposite the full stop (:) and the key opposite the + immediately afterwards. If the index of both communicator and indicator correspond, the connections will be right; but should the hand of the indicator be either in advance or behind the + one space, the connecting wires must be reversed.

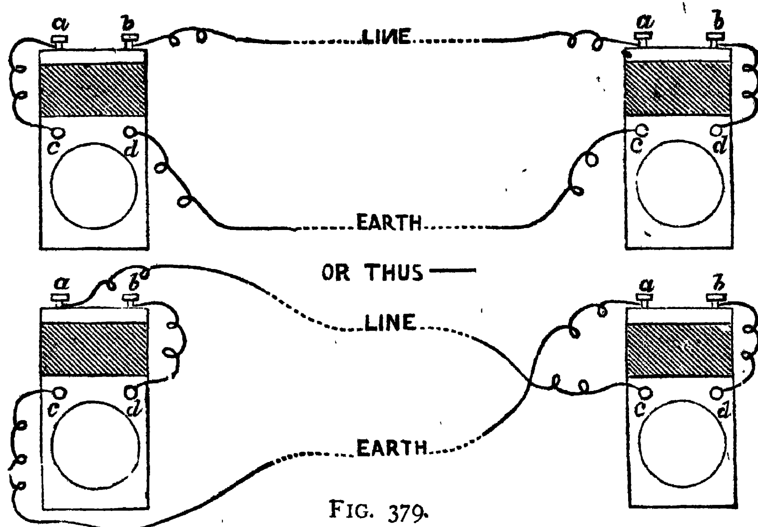


FIG. 379.

a being now joined up to *d*, and *b* to *c*, the instruments will be found to correspond in the revolution of their pointers round the dials. The line wire may now be connected to the instruments by removing one of the short wires at each station, and substituting the line wire and earth wire, as shown at *a b* and *c d*. The same signal of passing the pointer from + to + is now to be sent from station to station, and if the index at the other station falls either one in advance or behind, the position of the line and earth wires at one station only must be reversed.

The hand of the indicator may be reset by gently moving the small button under the face backward and forward between the thumb and finger.

When more than two stations require to be connected up in the same circuit, the above rules are to be observed with reference to the signals from + to + at each successive station, the connections appearing thus (Fig. 380)—

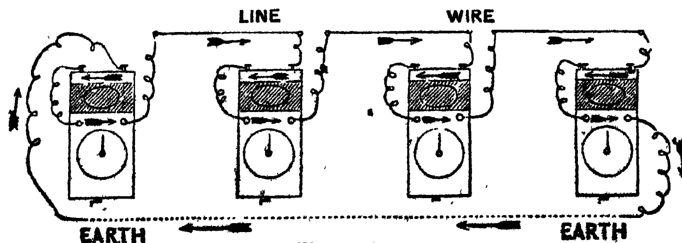


FIG. 380.

When several stations are in the same circuit, it will often be found convenient to introduce the switch, enabling the operator to send up and down the line in either direction, without interrupting the communication of those stations situated in an opposite direction to that in which he is speaking. The

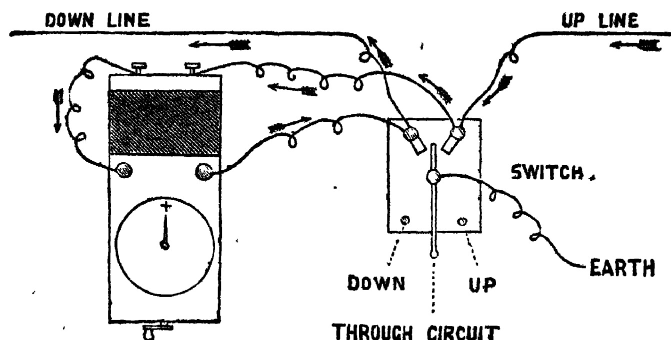


FIG. 381.

manner of connection will be seen by reference to the drawing. This arrangement will enable several stations to communicate with each other at the same time.

a——*b*——*c*——*d*——*e*——*f*——*g*——*h*

For instance, while *a* is speaking to *b*, *c* can talk to *d*, *e* with *f*, and so on. This system requires that each station has its own signal or preface for calling attention, and that when no station is called either up or down the line, the handle of the switch remains on the *through circuit*, as shown in the diagram. The switch is generally adapted to the peculiar requirements of the line.

When alarums or bells are used to call attention, they must be placed in circuit by connecting their binding-screws to the two lower binding-screws at the back of the indicator. The alarum may be placed at any distance from the instrument, in the most convenient position for calling attention. The switch, *x*, of the indicator should point to A, alarum, when no messages are being sent, but be turned to T when operations begin.

Instructions for working the Telegraphs.—The following summary of rules for working the telegraph may be advantageously introduced here:

1. The handle in front of the instrument (Fig. 377), which causes the armature of the magnet to rotate, must be kept in *continuous* motion by one hand, while the fingers of the other are employed to manipulate the stops or keys. Care must be taken not to intermit the motion until the end of the message.

2. A key need not be continuously pressed down; it will suffice merely to touch it; but another key must not be pressed down until the index or pointer has arrived at the letter previously indicated.

3. The same key cannot be pressed twice down in succession; to repeat a letter it is necessary to touch the preceding key, and, without waiting for the arrival of the index, to touch again the proper key.

4. Before commencing to send a message, the index of all the instruments must point to +. To bring the telegraph to this position when out, the small

pin or button on the face of the telegraph must be moved alternately backwards and forwards between the finger and thumb until the index stands at +.

5. If by inadvertence the index of the communicator has been left at a letter, it must be brought to the cross before the telegraph is adjusted.

6. The pointer of the alarum must invariably, when the instrument is not in use, be turned to the letter A.

7. To call attention for the purpose of sending a message, first turn your own alarum off, then rotate the handle of the communicator and let the needle pass from + to +. This will ring the bell at the other end. Wait an interval of time sufficient to allow of reply. If no reply, continue to call in the same manner.

8. Receiver will notify his attention by repeating the signal.

9. The receiver will then turn off his alarum, by passing the pointer from letter A to T.

10. A short time must be allowed the receiver before sending, to enable him to put his indicator in accord with his transmitter, if it be wrong.

11. At the end of each word the needle to be brought to the +.

12. Should the receiver not understand, he will send the letter R for repeat, prior to giving +. The sender will then repeat the last word.

13. Every initial letter or part of a word used for abbreviation must be followed by the full stop, and the full stop must be given at the end of each sentence.

14. At the end of message, needle to be turned from + to + twice.

15. Receiver to repeat this double revolution.

16. If by accident the needle of the indicator becomes misplaced, so as to render a message unintelligible, the receiver must break in by pressing down several keys in succession. The sender will immediately stay sending. Both receiver and sender will then set needles at +, and receiver will give repeat, R.

17. To signify figures, use the semicolon, and then the +, before and after them.

Instructions for keeping the Instruments in order.—When the telegraph is in operation, the handle of the communicator should be turned at a uniform rate of 120 revolutions per minute, and the finger-keys should not be depressed when the handle is at rest.

The working parts and bearings of the communicator will require occasionally to be oiled with good watch-oil, procured from any respectable watchmaker. If the oil is good, and the telegraph moderately used, the instrument will work eight or ten months without touching; but, when in constant use, it is desirable to apply a little oil regularly every two months. Access for this purpose may be obtained to the interior of the communicator by unscrewing the bottom of the communicator. The various parts to be oiled are shown in the annexed diagram at *a*, *b*, *c*, *d*; and by dipping the point of a penknife into the oil, it may be neatly applied in small quantities where desired.

If the centre, *b*, has become worn by constant revolution, and causing the armature, *e*, to touch the iron prolongations of the magnet, the handle will work stiffly or stop altogether. This may be remedied by tightening slightly the screw, *g* (Fig. 382), with a pair of small pliers, or other means sufficient to free the armature from contact with the poles of the magnet.

After long use, the watch-chain, which runs round the rollers on the lower plate, for the purpose of mechanically raising each key, after it has been depressed by the hand, may become too slack; this is remedied by slightly

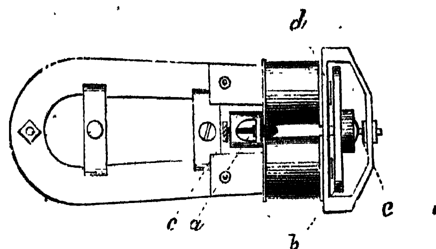


FIG. 382.

tightening the screw, A, attached to a lever carrying an extra roller, care being taken to leave sufficient slack in the chain to allow of one key always remaining depressed, as shown at B (Fig. 383).

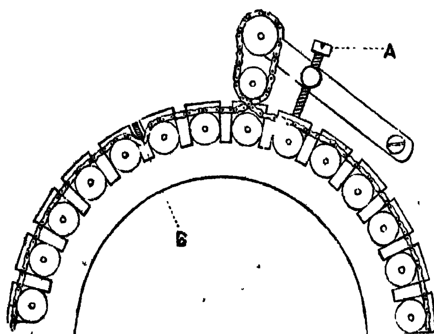


FIG. 383.

If it becomes necessary to take the communicator to pieces (this operation had always better be performed by a clock or watch maker, or other experienced person), the bottom of the case must be taken off first, and the little ivory number-plate in front of the instrument pushed out from the inside. This will enable the position of the wheel and pinion to be marked through the hole of the number-plate, by making a scratch (Fig. 384), as at *x*, across both, care being taken in putting together that the marked parts of the wheels are placed as before. The magnet may then be taken out, having previously unscrewed the wires leading from the coils. The brass casing which covers the upper portion of the mechanism is now to be unscrewed, and the ring with the glass, which is only sprung on, removed; then the dial card and plate. Unscrew the four pillars below, and, after the whole frame has been taken off the wooden case, all may be taken to pieces. It will be necessary to mark the

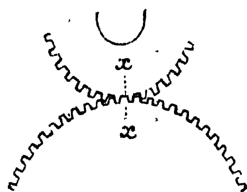


FIG. 384.

position of the two wheels, *h* and *i*, by a scratch across both, before taking that portion asunder. Oil must be put to the teeth of the wheel *k*, and also to *n*, *m*, *o*, and *p* (Fig. 385.)

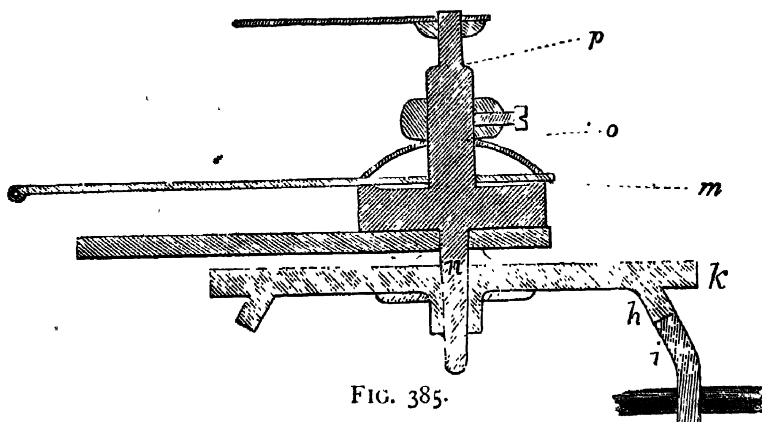


FIG. 385.

The operation of putting together is as follows:—First put the centre arbor and all upon it in the frame, and secure the same by the four pillar screws. Then place the finger-keys, the dial-plate, the springs for the keys, the dial, the index, and the glass together, and fix the whole on the wooden case. Lastly, place the magnet in its proper position, and, when all is ascertained to be correct, screw on the brass casing and the wooden bottom of the instrument.

The indicator and alarum may be taken to pieces, when necessary, and put together again, by marking the proper position of the several parts. In the indicator, pivots only require to be oiled, and that in very small quantities. The indicator, when good oil has been used, will work without attention for two or three years.

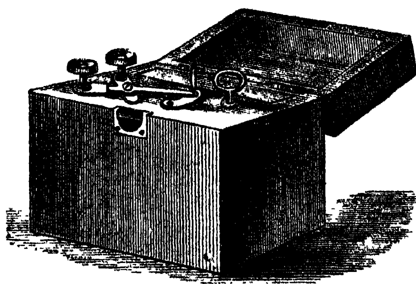


FIG. 386.—*Wheatstone's Bell in box, and ready for Military or other Service.*

Professor Wheatstone's instruments have been adopted by the army authorities, and are made, as in Fig. 377, p. 397, very portable and wholly independent

of all battery power, the trouble of putting batteries together, the supply of acids, breakage, and all the trouble that would be multiplied tenfold in the hurry of the battle-field. These instruments, as already described, work by a current developed by magnetism and by the use of steel magnets; they are made very strong and substantial, and are well calculated to bear the wear and tear of military operations conducted in the field.

The bell is rung, as nearly all other electric bells are rung, by clockwork wound up, but stopped by a "detainer." Directly the detent is removed by the current, the bell rings.

The same instruments, connected with enlarged dials, are used on board the iron-clads. We show an enlarged dial, and can easily understand how quickly the commander's orders could be conveyed to the engine-room.

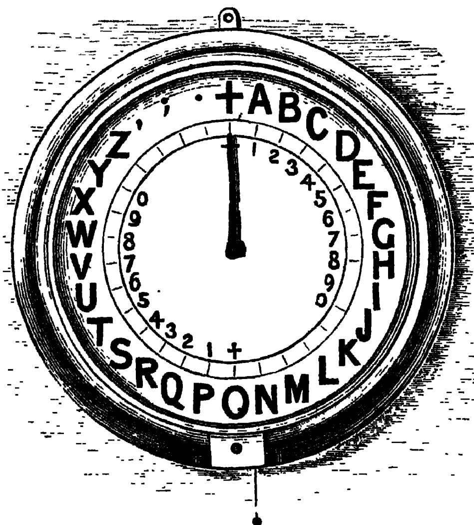


FIG. 387.—*Wheatstone's enlarged Dials, such as are used in the Engine-rooms of Ships of War.*

The dials, of course, would have special orders printed on them, being those given constantly in the navigation of these immense vessels.

In a very short time, similar dials will be placed in the various rooms occupied by members in the House of Commons, and the dials will show what business is in progress and what has been done. The business to be transacted, being printed in a circular form, is laid upon the dial, and the hand points to that in progress, whilst all behind it is over.

The steering of the iron-clads is also to be conducted with the assistance of similar dials.

One of the most useful of Sir Charles Wheatstone's elegant and beautiful inventions is the instrument he has supplied to the editor of "The Times" newspaper to record the number of copies printed and printing. The editor

reads in his own room the progress of that great undertaking, the daily printing of "The Times."

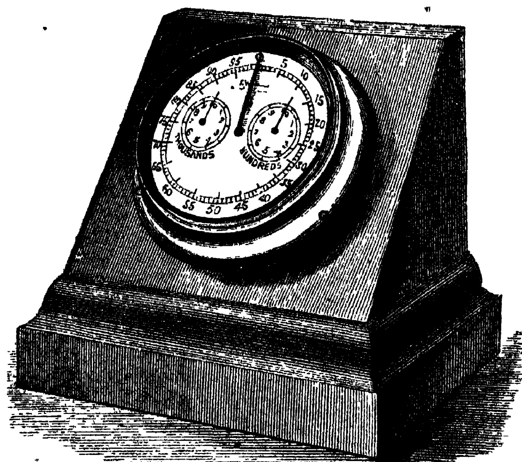


FIG. 388.—*Wheatstone's Recording Instrument for Newspaper Offices or Public Buildings.*

This instrument will record from ten thousand to one million copies. The same contrivance the writer hopes to be able to adopt at the Polytechnic, so that, without moving from his office, he will be able to know the number of persons in the building.

These instruments culminate to their highest degree of perfection in the inventions of 1858 and 1867, viz., Wheatstone's Fast-speed Automatic Telegraph, of which the inventor gives the following particulars:

"My invention consists of a new combination of mechanism for the purpose of transmitting through a telegraphic circuit messages previously prepared, and causing them to be recorded or printed at a distant station. Long strips or ribbons of paper are perforated, by a machine constructed for the purpose, with apertures grouped to represent the letters of the alphabet and other signs. A strip thus prepared is placed in an instrument, associated with a rheomotor (or source of electric power), which on being set in motion moves it along, and causes it to act on two pins in such manner that, when one of them is elevated, the current is transmitted to the telegraphic circuit in one direction, and when the other is elevated, it is transmitted in the opposite direction; the elevations and depressions of the pins are governed by the apertures and intervening intervals. These currents, following each other indifferently in the two opposite directions, act upon a printing or writing instrument at a distant station, in such manner as to produce corresponding marks on a ribbon of paper moved by appropriate mechanism.

"I will proceed to describe more particularly the several parts of this telegraphic system, observing, however, that each part has its independent originality, and may be associated with other apparatus already known.

"The first improvement consists of an instrument for perforating the slips

of paper with the apertures in the order required to form the message. The slip of paper passes through a guiding groove, at the bottom of which an opening is made sufficiently large to admit of the to-and-fro motion of the upper end of a frame containing three punches, the extremities of which are in the same transverse line. Each of these punches is capable of being separately elevated by an appropriate finger-key. By the pressure of either finger-key, besides the elevation of its corresponding punch in order to perforate the paper, two different movements are successively effected—first, the raising of a clip, which holds the paper firmly in its place, and, secondly, the advancing motion of the frame containing the three punches, by which the punch which is raised carries the ribbon of paper forward the proper distance during the reaction of the key consequent on the removal of the pressure; the clip first fastens the paper, and then the frame falls back to its normal position. The two external keys and punches are employed to make the holes which, grouped together, represent letters and other characters, and the middle punch to make holes which mark the intervals between the letters. The perforations in the slip of paper appear thus:

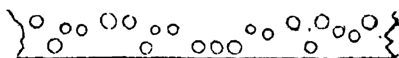


FIG. 389.

"The second improvement consists of an apparatus which may be called the transmitter, the object of which is to receive the slips of paper prepared by the previously described instrument or perforator, and to transmit the currents produced by a voltaic battery or other rheomotor in the order and direction corresponding to holes perforated in the slip; this it effects by mechanism somewhat similar to that by which the perforator performs its functions. An eccentric produces and regulates the occurrence of three distinct movements: 1st, the to-and-fro motion of a small frame, which contains a groove fitted to receive a slip of paper, and to carry it forward by its advancing motion; 2nd, the elevation and depression of a spring clip, which holds the slip of paper firmly during the receding motion, but allows it to move freely during the advancing motion; 3rd, the simultaneous elevation of three wires placed parallel to each other, resting at one of their ends on the axis of the excentric, and their free ends entering corresponding holes in the grooved frame; these three wires are not fixed to the axis of the excentric, but each of them rests against it by the upward action of a spring, so that when a light pressure is exerted on the free ends of either of them, it is capable of being separately depressed. When the slip of paper is not inserted, and the excentric is in action, a pin attached to each of the external wires passes, during each advancing and receding motion of the frame, from contact with one spring into contact with another spring, and an arrangement is adopted, by means of insulations and contacts properly applied, by which, while one of the wires is depressed and the other remains elevated, the current passes from the voltaic battery to the telegraphic circuit in one direction, and passes in the other direction when the wire before elevated is depressed, and *vice versâ;* but while both wires are simultaneously elevated or depressed, the passage of the current is interrupted. When the prepared slip of paper is inserted in the groove, and moved onwards, whenever the end of one of the wires enters an aperture

in its corresponding row, the current passes in one direction, and when the end of the other wire enters an aperture of the other row, it passes in the other direction; by this means the currents are made to succeed each other automatically in the proper order and direction to give the requisite variety of signals. The middle wire only acts as a guide to the paper during the cessation of the currents.

"The wheel which drives the excentric may be turned by hand or by the application of any motive power. Instead of a voltaic battery, a magneto-electric or an electro-magnetic machine may be employed as the source of electric power. In this case the transmitter and the magneto-electric or electro-magnetic machine form a single apparatus moved by the same power, and they are so adapted to each other, that the shocks or currents are produced at the moments the pins of the transmitter enter the apertures of the perforated paper.

"The transmitters just mentioned require only a single wire of communication, and currents in both directions are available for printing the signals; but in some cases it may be advantageous to employ two telegraphic wires, and to use the inversions of current to bring back the pens or markers without the aid of reacting springs. In this case the only modification of the apparatus required is in the disposition of the insulations and contacts necessary to transmit in their proper order the currents from the rheomotor into the two wires.

"The third improvement is in the recording or printing apparatus, which prints or impresses legible marks on a strip of paper, corresponding in their arrangement with the apertures in the perforated paper. The pens or styles are depressed and elevated by their connection with the moving parts of the electro-magnets; they are entirely independent of each other in their action, and are so arranged that, when the current passes through the coils of the electro-magnets in one direction, one of the pens is depressed, and when it passes in the contrary direction the other pen is depressed; when the currents cease, light springs restore the pens to their usual elevated positions. The mode of supplying the pens with ink is as follows:—A reservoir, about an eighth of an inch deep, and of any convenient length and breadth, is made in a piece of metal, the interior of which may be gilt, in order to avoid the corrosive action of the ink placed in it. At the bottom of this reservoir are two holes, sufficiently small to prevent by capillary attraction the ink from flowing through them. The ends of the pens are placed immediately above these small apertures, which they enter when the electro-magnets act upon them, carrying with them a sufficient charge of ink to make a legible mark on the strip of paper passing beneath them. The motion of the paper ribbon is produced and regulated by apparatus similar to those employed in other register or printing telegraphs.

"Instead of reacting springs for restoring the position of the pens, the attractive or repelling force of small permanent magnets may be employed. All the essential parts of my new recording or printing telegraph are included in the previously mentioned three improvements. The following improvements are either auxiliary or substitutions for parts already mentioned.

"The fourth improvement is an instrument which I call a translator; its object is to translate the telegraphic signs, consisting of successions of points or marks, adopted in this system, into the ordinary alphabetic characters. In the system I have adopted, limiting the number of points in succession to four, thirty distinct characters are represented.

"The instrument presents externally nine finger-stops, eight of which are arranged in two parallel rows, four in each, and the remaining one is placed separately.

"The principal part of the mechanism within is a wheel, on the circumference of which thirty types are placed at equal distances, representing the letters of the alphabet and other characters; other mechanism is so disposed and connected thereto, that when the keys of the upper row are respectively depressed, the wheel is caused to advance 1, 2, 4, or 8 steps or letters, and when those of the lower row are in like manner depressed, the wheel advances respectively 2, 4, 8, or 16 steps. By this disposition, when the stops are touched successively in the order in which the points are printed on the paper—touching the first stop for one point, the first and second for two points, &c., and selecting the stops of the upper or lower row, according as the point is in the upper or lower row of the printed ribbon—the type wheel will be brought into the proper position for placing the letter corresponding to the succession of points over a ribbon of paper. The ninth stop, when it is pressed down, acts to impress the type on the paper, to cause the advance of the paper, in order to bring a fresh place beneath the type-wheel, and subsequently to restore the type-wheel to its initial position.

"The fifth improvement is a modification of the electro-magnets of the instrument of the third improvement, which enables the pens to go back to their normal positions when the currents in the telegraphic circuit cease, without the aid of reacting springs or permanent magnets. An extra coil of wire is wound round each of the electro-magnetic bars, which act on one side of each of the double magnetic needles appropriated to the two pens. These coils are entirely insulated from those connected with the telegraphic circuit, and form together a short local circuit, in which a feeble voltaic current continually circulates, in consequence of the interposition of a small rheomotor; by this current the needles are held, when no current exists in the telegraphic circuit, constantly attracted towards these electro-magnets. When, however, the current transmitted through the telegraphic circuit acts on the coils, besides its direct action to cause the deflection of one of the double needles and the detention of the other, it neutralizes the current of the local battery in that electro-magnet where its effect for the time would be disadvantageous.

"The sixth improvement consists in the application of ribbons of paper prepared by the perforator, and passed through the transmitter as heretofore described, to produce the successive motions of a magnetic needle or needles corresponding to the signals required, whether separately employed for this purpose or in conjunction with the printing apparatus already mentioned."

Even these beautiful instruments were not considered perfect by the indefatigable inventor, and we again find him, after a most severe illness, recording, in 1867, further great improvements in the mechanism of all their parts.

IMPROVEMENTS IN ELECTRIC TELEGRAPHS, AND IN APPARATUS CONNECTED THEREWITH.

"My present invention (1867) consists in certain improvements in the various instruments constituting the electric telegraph system described in the specification of the patent granted to me on the second day of June, A.D. 1858, No. 1239.

"This system comprises three distinct apparatuses: first, a perforating

machine for preparing the messages to be sent on the strips of paper or other suitable material;

"Second, a transmitter, or apparatus for receiving the strips of paper so prepared, and for transmitting the currents produced by a voltaic battery, magneto-electric machine, or other rheomotor, in the order corresponding to the holes perforated in the strip, the direction and sequence of these currents being governed by pins, or other suitable apparatus, disposed so as to enter the perforations, and operating in a manner analogous to that in the mechanism of a Jacquard loom, and the strip being advanced intermittingly by the action of pins or other apparatus appropriated for that purpose;

"And, third, of a recording or printing apparatus adapted to print or impress marks on a strip of paper, such marks corresponding in their arrangement with the currents transmitted to the telegraphic line and with the apertures in the perforated paper.

"Having separately described each system of recording telegraphs, with the improvements which form the objects of the present specification, I proceed to designate those points which I specially claim as new.

"First, the modification of the perforator for the dot-printing telegraph, which enables it to prepare the strips of paper with an uninterrupted series of central apertures; this modification, described as the first improvement, consists of the mechanism being so arranged that when either of the keys corresponding with the outer apertures is depressed, besides acting on its own punch, it carries with it the punch which corresponds with the central apertures, while the latter is alone acted upon by means of another key causing the perforation only of a single aperture at a time.

"Second, the modification of the perforator, described as the fourth improvement, having five punches, and the mechanism so arranged that, when the first key is pressed, three of the punches in the order described are simultaneously acted upon; when a second key is depressed, four of the punches are in like manner simultaneously acted upon; and when a third key is depressed, the single punch only of the central line is acted upon. I claim also, in connection with this arrangement, the mechanism by which when either the first or third keys are pressed down the paper advances only a single space, and when the second key is depressed it advances two spaces; but be it understood that I do not claim the advance of the paper by unequal spaces, unless in connection with the arrangement of the punches described.

"Third, the additions of extra keys to the preceding modification of the perforator, with additional punches, described in the fifth improvement, which are so arranged that each additional key when depressed, while it punches simultaneously all the required apertures, shall advance the paper at once three, four, or more steps, so that all the perforations may be simultaneously made which are necessary to cause lines of the various required lengths to be marked or printed by the receiving instrument.

"Fourth, the modification of the transmitter, described as the second improvement, whether actuated by a magneto-electric machine or by a voltaic battery, in which the central needle alone has a to-and-fro motion for the purpose of propelling forward the strip of paper by means of the central apertures alone, and not also by means of the external apertures and outer pins, as described in the second improvement of the specification of my patent, No. 1239 (A.D. 1858).

"Fifth, the modification of the transmitter, described as the sixth improve-

ment, which is adapted to send into the telegraphic circuit short currents at various intervals and alternately in opposite directions, so as to determine the occurrence of printed lines and intervals of various lengths in the receiving instrument: in this modification one current-governing needle has a to-and-fro motion simultaneously with the central needle, while the other has no such motion, the latter acting only while the paper is at rest, and the former while it is in motion.

"Sixth, the modification of the transmitter, described as the eighth improvement, which is suited to send into the telegraphic circuit currents of various lengths in one direction only in a different way to that described as the seventh improvement in my patent, No. 2462 (A.D. 1860). The characteristics of this new method are, first, that lines of any lengths can be produced, instead of lines of two different lengths only; second, that the short lines occupy a shorter space on the paper than the long lines do; and, third, that strips of paper prepared by the perforators of the third and fourth improvements may be employed to regulate the motions of the needles in order to produce the required effects.

"Seventh, the modification of the dot-printing receiving instrument, described as the third improvement, in which the pens or markers are acted upon by one set of electro-magnets and magnetic bars, instead of by two sets, as described in the specification of my patent, No. 1239 (A.D. 1858).

"Eighth, that modification of the printing apparatus of the receiving instruments of the second and third systems described as the eighth improvement, by means of which lines of various lengths are printed with great rapidity, certainty, and distinctness. The characteristic distinction of this mode of printing is, that the inking-disc and tracing-disc are both independently kept in motion by the maintaining power, and are not in actual contact with each other, and that the ink is retained on the circumference of the inking-disc by capillary attraction."

We now give the description of the three instruments:

I. The perforator.
II. The transmitter.
III. The recorder.

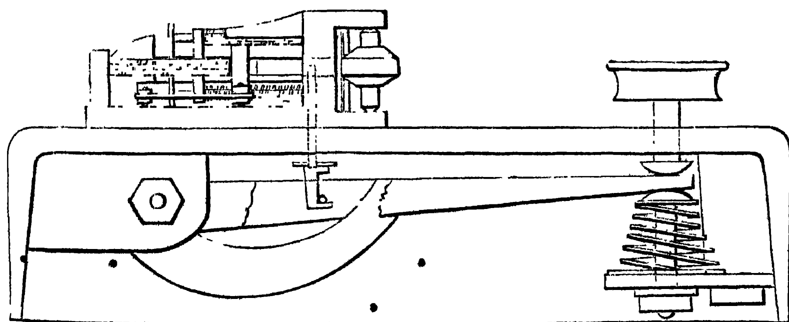


FIG. 390.—*The Perforator* (1867).

"The present improvement provides for the continuity of the middle perforations of the paper strip. The punching-plate carries three punches (Fig. 391),

placed transversely to the path of the paper through the machine. Three lever finger-keys act upon the punches in such a manner that whenever either of the outer keys is depressed, it acts upon the punch which belongs to it, and at the

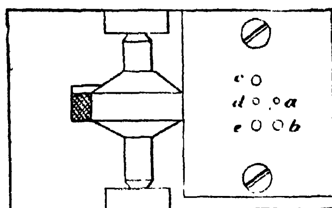


FIG. 391.

same time carries with it the middle punch by means of a collar which is fixed thereto, and simultaneously perforates the two apertures; but the depression of the middle key acts upon the middle punch alone, and perforates a middle aperture only, which is equivalent to a space in the receiving instrument. On the removal of pressure from any finger-key, the corresponding punch or punches is or are restored to its or their normal positions by means of a reacting spring or springs. A lever and link arrangement, moved by either of the three keys, draws back the paper-moving lever during the depression of a key; the release of a key permits a reacting spring to force the paper-moving lever forwards and to advance the paper one step, the said lever having a rough end next to the paper strip for that purpose: this mechanism propels the paper quite independently of the middle row of holes.

"Fig. 392 is a perspective view of a transmitter arranged to work with two line wires; in this instrument, besides the necessary change in the insulations and contacts, the mechanical arrangements are slightly varied, the construction shown being more convenient when two line wires are employed than that first described. *a* is a permanent magnet, and *b* is an armature mounted on an axis *c*, so as in revolving to pass in front of the poles of the magnet. On the axis *c* there is a toothed wheel, *d*, which drives the pinion *e* on the vertical axis *f*, so that this axis makes twice as many revolutions as the axis *c*; at the upper end of the axis *f* is a cam, *g*, arranged to act on the pin *h*, which is mounted on a rocking-frame similar to the rocking-frame of the transmitter already described. The pin *h* is kept in contact with its cam *g* by a spring *i*. The form of the cam is such that the forward motion of the frame is gradual, but its return motion takes place as rapidly as the spring *i* will react. *j* is another cam on the axis *f*; it comes in contact with a projection on the lever *k* just as the return motion of the rocking-frame is going to take place, and so causes this lever to draw down the three needles carried by this frame. At the same time the tail of the lever *k* presses on the end of another lever *l*, which is fixed to the spring-clip *m*, and so causes the clip, by turning slightly on its axis, to nip the paper under it. It will be seen that the two outside needles carried by the rocking-frame have projections from their lower ends, and when they are allowed to rise by the perforated paper, as before explained, their ends come in contact with the springs *n* and *o*, which are insulated from the rest of the instrument, and are in communication with the two line wires. On the

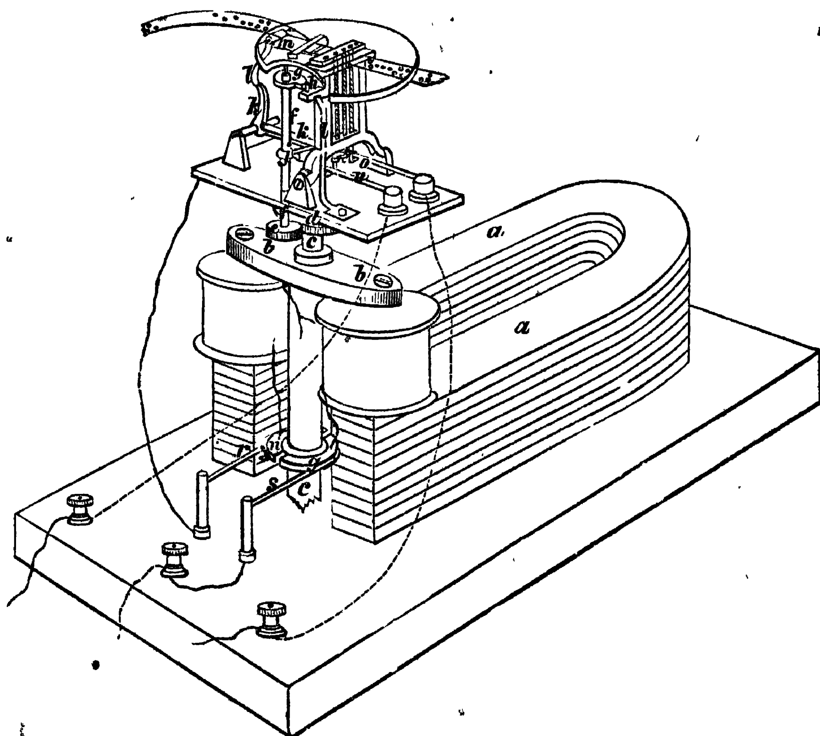


FIG. 392.—*The Transmitter* (1858).

axis *c* a metal disc is mounted; it is made in two parts, *p* and *q*, which are insulated from each other and from the axis. *r* and *s* are two springs, which press on the periphery of the disc as it revolves; the spring *r* is in metallic communication with the working parts of the instrument, and the spring *s* is insulated from these parts, but is put into metallic connection with the earth. When one of the needles of the rocking-frame comes into contact with its corresponding spring, *n* or *o*, it brings the line wire in connection with the spring into metallic communication with the working parts of the instrument, and any currents or shocks transmitted to these flow into the line wire. From the construction of the apparatus, the contact between the needles of the rocking-frame and their corresponding springs when established lasts during half a revolution of the axis *c*, and in this period two currents in opposite directions are transmitted into the line wire. The first current acts to bring one of the pens or markers of the receiving instrument into contact with the surface to be marked, and the second current to bring this pen or marker to its original position. It is evident that, if necessary, the instrument above described may be worked with one line wire only, without any change being made in the instrument; all that is necessary is that, in perforating the strip

for the message, only one of the outside finger-keys of the perforator should be employed (the alphabet or signs employed being modified accordingly). Or the perforating instrument and the transmitting instrument may both be modified, if desired, so as to be suitable only for working with one line wire, by constructing the perforator with two in place of three finger-keys and punches, and the transmitter with two in place of three needles."

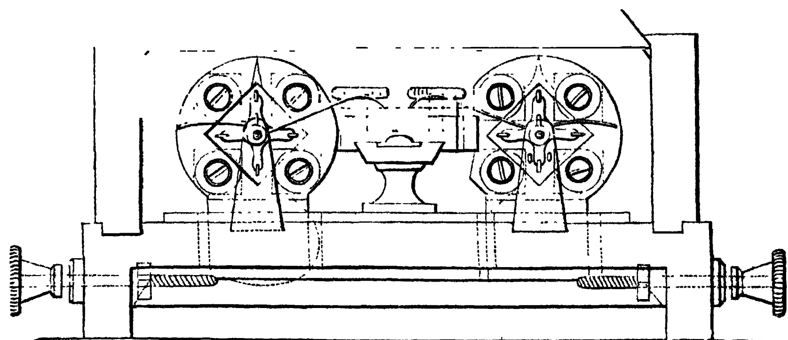


FIG. 393.—*The Recording or Printing Instrument* (1858).

Another improvement is in the recording or printing apparatus; but as the chief parts of this instrument have already been described with sufficient minuteness, it is only necessary to refer our readers to page 406 for the details of the beautiful mechanism which regulates the marking of the slips of paper and the supply of ink to the dotting apparatus.

The improved instruments are now working between London and Newcastle, Edinburgh, Manchester, and Glasgow; and they can send and print *messages from seventy to one hundred and twenty words per minute*, according to their exigences. They are also used in connection with the submarine cable extending from Newcastle to Denmark.

SIR CHARLES WHEATSTONE'S LAST AND MOST COMPLETE TELEGRAPHIC APPARATUS,

AND OTHER BEAUTIFUL APPLICATIONS OF ELECTRICITY—THE CHRONOSCOPE AND TELEGRAPH THERMOMETER FOR GREAT ALTITUDES.

No. 1.	A.	B.	C.	D.	E.	F.	G.	H.	I.	J.	K.	L.	M.	N.	O.
No. 2.	A.	B.	C.	D.	E.	F.	G.	H.	I.	J.	K.	L.	M.	N.	O.
No. 3.	A.	B.	C.	D.	E.	F.	G.	H.	I.	J.	K.	L.	M.	N.	O.

No. 1.	P.	Q.	R.	S.	T.	U.	V.	W.	X.	Y.	Z.
No. 2.	P.	Q.	R.	S.	T.	U.	V.	W.	X.	Y.	Z.
No. 3.	P.	Q.	R.	S.	T.	U.	V.	W.	X.	Y.	Z.

FIG. A.—*The various Telegraphic Alphabets.*

No. 1.—The Dot Printed Alphabet, and also the perforated slip for the same system, with the transmitting perforations omitted.
No. 2.—The Line or Morse Printing Perforated Slip, with the transmitting perforations omitted.
No. 3.—Line or Morse Printed Alphabet.

*. When Sir Charles Wheatstone turned his attention to fast-speed telegraphs, the result was the dot printing. He attained 700 letters per minute; but the telegraph companies objected to it, because it necessitated the clerks learning the new alphabet, the dots being in two lines (No. 1, Fig. A), the lower dot taking the place of the dash in the line or Morse alphabet. In addition to the above objections, it is not suited for submarine cables requiring reversals for rapid working; therefore, Sir Charles brought out a transmitter to work the inking Morse. But words could be transmitted quicker than the instrument would print; therefore, it remained for Sir Charles to bring out a rapid printer,

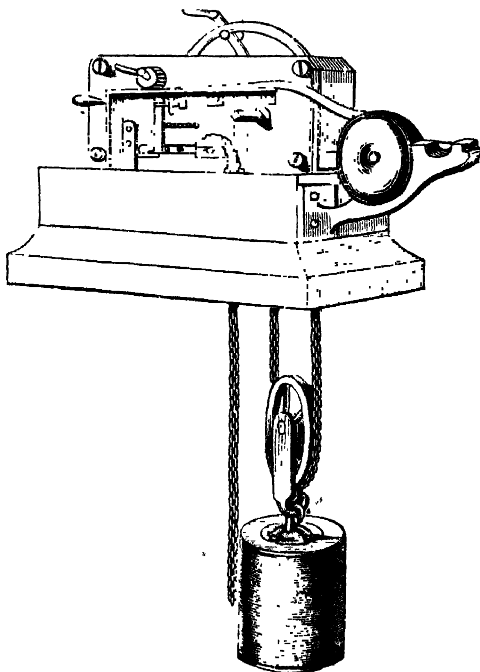


FIG. B.—*The Line-printing Transmitter.*

which he accomplished, and it is now known by the name of the "line-printer," printing the dot and dash alphabet (No. 3, Fig. A), such as is used by all telegraph companies, printing 600 letters per minute; the dot and line printing differing especially in this respect—the line currents always being inverted alternately; in the dot, three or four currents in the same direction sometimes follow each other.

THE LINE TRANSMITTER WITH MAINTAINING POWER (Fig. B), is a modification of the transmitter described as the sixth improvement for receiving the strip prepared by either of the perforators described as the fifth improvement, and transmitting voltaic currents along the telegraphic conductor to the receiving instrument at the distant station, in accordance with the arrangement of the

perforations in the paper strip (motion being produced by a weight); the propulsion of the paper strip and the makings of the contacts with the batteries are accomplished by the same power; and, by means of levers, beam, eccentric, and springs, the upper ends of two vertically moving pins, being alternately pressed against the paper, are free to enter the perforations, if any present themselves; or, being prevented from entering the paper by the absence of apertures, they regulate the succession, frequency, and direction of the electric currents sent into the telegraphic circuit.

The action of the pins in conjunction with the paper strip is as follows: the

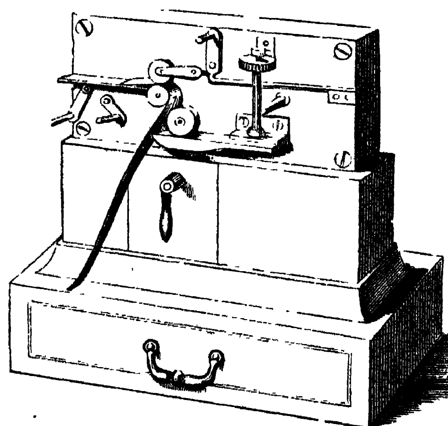


FIG. C.—*Line Printer or Receiver.*

only means of propulsion of the paper is by the pins of a star-wheel entering the middle perforations, and by its rotation moving the paper forward, the strip being held down by a broad-toothed wheel pressing it against the paper-ledge, the vertically moving pins entering the notches in the before-mentioned wheel, pass through an aperture in the paper, and are carried forward by it, thus not interfering with the duration of contact at the lower end of the pins; the reacting springs restore them to their normal position on their downward movement, effected by the levers to which they are attached receiving an up-and-down motion from an oscillating beam, connected with an eccentric driven by the maintaining power; and, on the arrival of an outer aperture on one side of the middle line of holes, the pin of that side will enter and transmit a current in one direction; and on the presentation of an aperture on the opposite side, the pin will also enter and transmit a current in an opposite direction, the apertures in the paper regulating the frequency, direction, and duration of the current sent into the telegraph line.

In the Line Printer or Receiver (Fig. C), the magnetic armatures are placed in a vertical position; the central axis is prolonged so as to carry the cross-piece, through an aperture in the extremity of which a horizontal rod passes; on this is mounted at one extremity the small, light tracing-disc, whilst the opposite end, which is loosely centred, so as to be capable of a slight lateral movement, carries a small toothed wheel; this wheel, gearing with the main-

taining power of the instrument, imparts a rotatory motion to the tracer, at the same time that the axis is capable of receiving a to-and-fro motion in a horizontal plane from the movement of the armatures and arm.

In the same vertical plane, and immediately beneath the tracing-disc, is an inking-disc, caused to rotate, by appropriate gearing, with the maintaining power of the apparatus: this disc revolves in a reservoir containing ink, or other suitable marking fluid. The periphery of the disc is slightly hollowed, and the edge of the tracing-disc just enters this hollow without contact or friction with the inking-disc; during the revolution of the disc, capillary attraction keeps the hollow full of ink, and a constant and uniform quantity will be supplied to the tracing-disc.

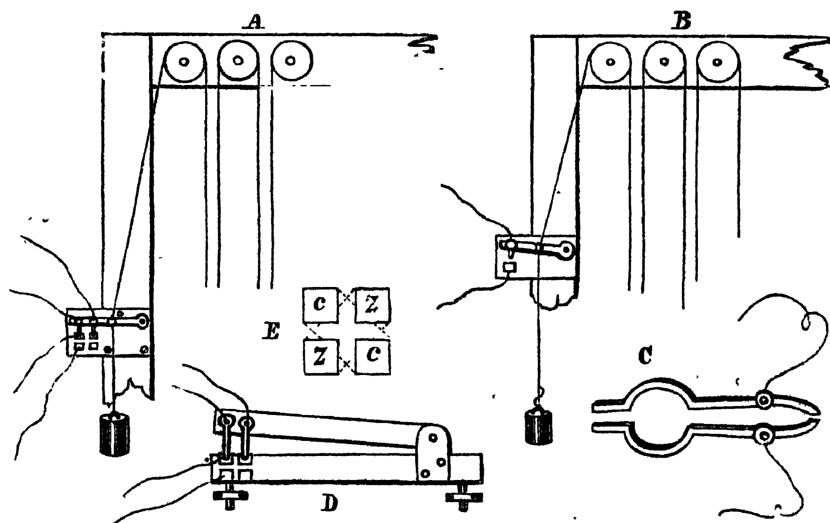


FIG. D.—*The various parts of Apparatus used with Wheatstone's Chronoscope.*

The paper intended to receive the marks is drawn forward at suitable speed over a roller in close proximity to one edge of the tracing-disc. It will be understood that a series of instantaneous alternate currents passing through the electro-magnet causes a to-and-fro motion of the tracing-disc, a current in one direction pressing the tracing-disc against the paper, where it will remain, by reason of the residual magnetism of the electro-magnets retaining the armatures in that position, until a current in the opposite direction withdraws the tracer from the paper. By this arrangement lines of more than two lengths can be printed with perfect accuracy in connection with the perforator with five keys described as the fifth improvement. Another remarkable instrument is

WHEATSTONE'S CHRONOSCOPE.—The various parts of this arrangement are shown at Fig. D, and employed to ascertain the velocity of projectiles. They will be readily understood when we describe the ball-holder and target used in the falling bodies experiments. A and B are enlarged parts of screens,

C is the ball-holder closed to receive the ball, each side being insulated. The electric circuit is not complete; but, at the moment of the release of the ball, the two sides will meet and complete the circuit, which, traversing in one direction, will start the chronoscope: this will continue running until the ball strikes the target, when it will reverse the current and stop it. The method of reversing is readily understood by E and D, Fig. D. Two springs are fixed to the target, which is hinged at one end, the other end falling when the ball strikes it. The springs slide over the reversing-piece, consisting of two poles of the battery, which are bridged over at the back, as indicated by the dotted lines, E.

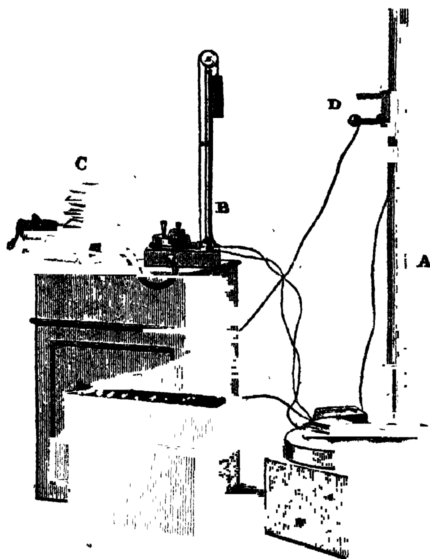


FIG. E.—*The Chronoscope in Elevation.*

Fig. E represents the chronoscope as arranged for indicating automatically the time occupied by falling bodies. A is a column, upon which the ball-holder slides, the target being placed at the base; B is the chronoscope, consisting of clockwork mechanism, with two dials, one divided into hundredths, and the other into thousandths, of a second, with hands like a watch, motion being communicated to it by a weight passing over a pulley, which is regulated by an escapement with a musical spring, tuned to a thousandth part of a second, caused to sound by the pressure of air from the bellows, C. The clockwork is in two distinct parts, the driving and the dial parts; they are made to gear by sensitive magnetic needles and an electro-magnet. One pole of the battery is connected with the ball-holder, the other with the target; two wires from the target connect it with the chronoscope, one wire connecting the ball-holder with the target. The poles of the battery are so arranged that on the release of the ball the electric circuit is completed, and the dials are brought into gear with the driving part; the current is reversed the instant the ball strikes the target, and

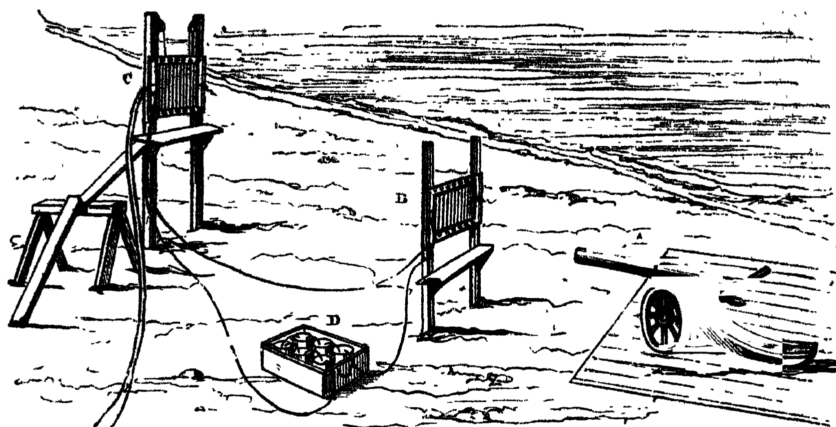


FIG. F.—*Wheatstone's Projectile Arrangement.*

The targets, B and C, connected with the battery, D, and Wheatstone's chronoscope, arranged to receive and indicate the velocity of the shot from the Armstrong gun, A.

the dials are disengaged, enabling the operator to read off the time by the hands, without the tedious calculation necessary by other means generally employed. The almost inexhaustible inventive faculty of Wheatstone, ever devising new or improving older inventions, is again displayed in his New Telegraph Thermometer (Fig. G).

This instrument was invented by Wheatstone to supply a scienific want, viz., the means of ascertaining, day or night, without making tedious ascents, the temperature of any lofty summit—such as that of Mont Blanc.

The cut (Fig. G) represents the general internal arrangement of the instruments requisite to ascertain the temperature at a distant point, two insulated wires connect them, the earth being used to form the third conductor.

The apparatus includes the thermometric arrangement, and also an electro-magnetic contrivance for converting the vibrations of magnetic needles between electro-magnets into a circular motion, for the purpose of altering the electric conduction from one circuit to another.

In order to indicate the temperature measured by the instrument above mentioned, there is an electro-magnetic arrangement, and also a permanent compound magnet with fixed coils, having an armature opposite to its poles, capable of being rotated by a handle, to produce a series of alternately inverted currents.

Fig. G, p. 419, represents the internal construction of both instruments; the dotted and other lines represent the wires necessary to conduct the electric currents. In the knob A, which is attached to the glass covering the dial, is contained a metallic thermometer, having a hand or pointer attached to its axis; and in the same line is an insulated axle, with arms, C and D, proceeding from it, a spiral spring tending to maintain the contact of the arm C with the hand B; under this axle is a toothed wheel, F, with a spring-catch, E, the said wheel gearing with the pinion G, connected by a spindle with the wheel H, mounted

on an oscillating arm proceeding from the axle, carrying the magnetic needles placed between two coils (only one is shown in the drawing) analogous to the indicator of the alphabetical telegraph (Fig. A). O K is a similar arrangement; M N is a magnetic machine.

When an observation is about to be made, the dial of the indicator is adjusted to zero by means of the rim P, and the handle N rotated, producing a series of positive and negative currents, which may be imagined to take the course indicated by the arrows, coming from a coil, passing through wire 6 to

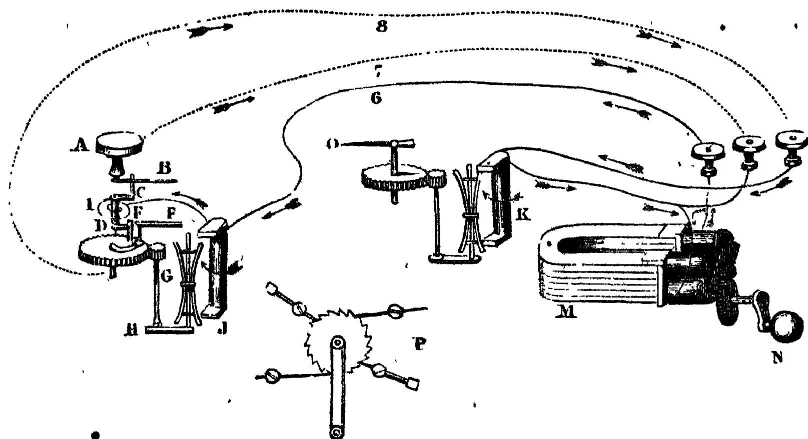


FIG. G.

the coils J, the short wire to the axle C D, to the hand B, and wire 7 to the coils of the magnets, thus completing the circuit, causing the needles between the coils J to oscillate by their alternate attraction and repulsion, communicating that motion by the arm H J to the wheel H, which, by its peculiar construction, will rotate, communicating that motion, by means of the pinion G, to the wheel F in the direction G E D; the pin E, pressing against the arm D, will draw away the arm C from the hand B; the piece D C will make a partial rotation on its axis, or describe an arc by the arms C D, the angle being the number of the degrees of temperature, thus breaking the circuit at C B, and completing it through D E; the wheel F, and wire 8, including the coils K, imparting motion to the hand or pointer O by the same means to those already described, which will continue until the catch E arrives at the pin L, corresponding to the zero in the scale of the instrument, when it will disengage the pin E from arm D, the spiral spring forcing arm C in contact with the hand B, thus restoring the circuits to their former condition.

When the circuit is complete through the wires 6 and 7, only the coils J come into action; but when the connections are made through wires 6 and 8, both coils are caused to act, moving the arm C in the thermometer from the highest point indicated on the dial to the zero, and in the indicator from the adjusted zero to the highest point, when the motion of the pointer will cease, indicating the state of the dial B A.

In a paper read by Sir Charles Wheatstone before the Academy of Sciences at Paris he thus sums up the advantages of his automatic printing telegraphic system:

"I will conclude by offering a few remarks on the advantages possessed by this system.

"Whatever practical dexterity may be acquired by a voluntary operator, the result arrived at will be far inferior to that obtained by the automatic process, which is only limited by the rapidity with which the recurring motions of the transmitter can be effected. By the present construction of the instrument, five times the quantity of signs at present used can be transmitted to moderate distances; though for very considerable distances this rapidity may be limited in conductors subjected to inductive influences by the tendency which rapidly recurring short currents have to coalesce.

"But even if there were no advantage in point of rapidity possessed by the automatic over the voluntary process of transmission, its other advantages would be incontestable. For the profitable working of a telegraphic line, it is necessary that the operator should manipulate as rapidly as is consistent with a correct transmission of the message: it requires great skill to become a proficient in such manipulations, even when the language in which the despatch is sent is quite familiar to the operator; but if he would send a despatch in a language unknown to him, or in cipher, he is obliged to proceed with caution and slowness. In my new system the prepared messages are transmitted with equal rapidity in whatever language or cipher they may be; and as the perforated bands may be prepared at leisure, and be subjected even to the revision of a corrector, guarantees of accuracy are obtained which cannot be afforded by the system of immediate voluntary transmission. Several clerks will be required to prepare messages for a single telegraphic line in constant activity; but, in an economical point of view, their time is of far less importance than the time occupied by the transmission of a message.

"Another advantage this new system possesses is that the same prepared message may be transmitted through any number of distinct lines, if not simultaneously, at least in such rapid succession as to be equivalent thereto; and besides, without any fresh labour, the same message may be retransmitted, if thought necessary; and service messages in constant use may be preserved for transmission whenever they may be required.

"Were this automatic system generally adopted, it might in many instances be more convenient to prepare the messages at the offices from which they are sent, the instrument for effecting this purpose being very portable and of small cost. The operations at the telegraph office would in these cases be limited to passing the perforated band through the transmitter at one station and receiving the printed message at the other, the translation as well as the preparation of the message devolving on the department of the administration to which it relates.

"In the present case it is not the question to substitute one kind of acquired skill for another kind equally difficult to attain, which would entail great labour on all the employés. The great practical dexterity at present required being dispensed with, and the principal and most laborious operation being entirely automatic, there is little to learn, though there may be something to forget."

THE ATLANTIC TELEGRAPH CABLE.

The resistance of a conductor of any given metal is *directly proportional to its length*, and *inversely proportional to its thickness* or cross section.

It was soon found to be necessary, in experiments with thousands of miles of cable or insulated wires, to adopt some standard or starting-point, in order to ascertain exactly the resistance of the whole.

The matter was put into the hands of a committee of the British Association, who determined that an English mile of pure copper wire, No. 16, should be the B. A. unit; they further constructed a wire of silver and platinum, because it was little affected by temperature, which they deposited as the standard of comparison, and this length of wire they estimated in figures to be 13·59 of the length of the copper wire. Bobbins upon which hundreds and thousands of miles of copper wire No. 16 would have to be wound would be too bulky and cumbersome to manage; it has, therefore, been arranged that German silver, an alloy of about 60 parts of copper with a fraction of lead, 25 zinc, and 15 nickel, should be employed, because it has about thirteen times less conducting power than the same-sized copper wire; consequently the standard unit would be represented as follows:

B. A. unit of German silver wire = 13·59 of an English mile.

The bobbins, having 13·59 of an English mile of German silver wire wound upon them, represent, therefore, a resistance equal to one mile.

The length of the great Atlantic cable, stretching between Valentia in Ireland and Newfoundland in America, a distance of 3,500 miles, is 1,858 knots, and each knot, equal to $7\frac{1}{3}$ nautical miles, has an electrical resistance, at a temperature of 75° Fahrenheit, equal to 4·272 of the above-named B. A. units. Consequently 1,858 knots, multiplied by 4·272, would give the resistance of the whole cable as 7,937 B. A. units; or, allowing for diminished resistance caused by the low temperature of the bed of the Atlantic, and deducting a certain number of units for that, we have, say, 7,500 B. A. units.

The resistance of the cable of 1865, according to Mr. Latimer Clark, is 7,604 B. A. units. The resistance of the last new cable, 1866, is 7,209 B. A. units. It is so much better, and the instruments are so vastly improved, that they can send from eighteen to twenty words per minute, instead of, as formerly, only two and a half. The new cable has three times more speaking power now it is immersed in the Atlantic than it had on board the Great Eastern.

At the commencement of the article on Electricity, great stress was laid upon the explanation of the phenomena of induction. The conducting wires of the Atlantic cable, formed of a strand of seven wires, each 0·048 inch in diameter, and together equal to a wire of 0·144 inch diameter, are surrounded with, and insulated by, gutta-percha.

Such being the case, it is easy to understand that, when conveying an electrical current, it must become charged like a Leyden jar. The wire is the inner metallic coating, the gutta-percha is equivalent to the glass, and the salt water outside the other metallic coating. This enormous Leyden jar measures in its inner coating about 425,000 square feet, and it was the charge maintained by the cable that seemed at first to negative and destroy all hope of sending messages quickly. This very property is now found to be most valuable, and

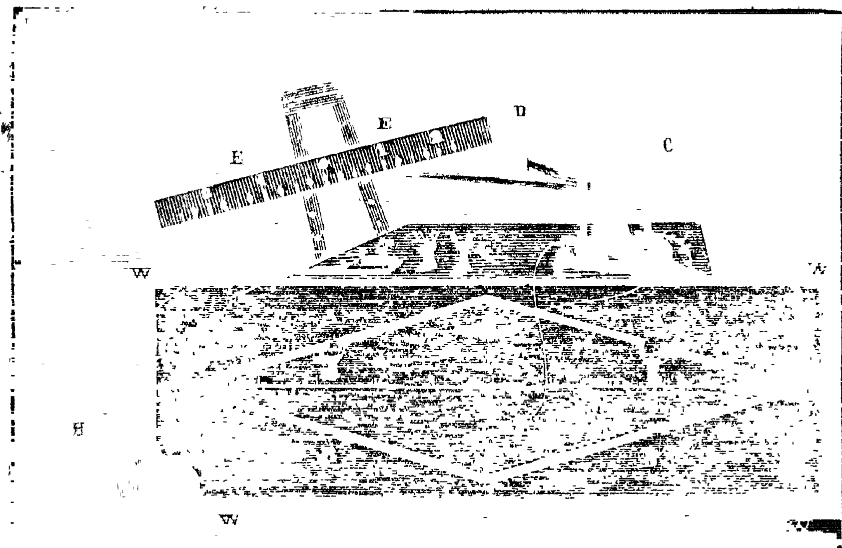


FIG. 394.—*Thompson's Reflecting Galvanometer Needle.*

C, The galvanometer; D, the oxy-hydrogen light; E E, the scale; W W W W, the Wheatstone bridge F, the key; G, extra-resistance coils; and H, the battery.

is made use of to expedite the sending of the signals, and in brief terms may be thus described:

The cable is first charged until, like a Leyden jar, it will bear no more. In order to send a message, it is discharged; and it is the latter operation, acting upon instruments of wondrous delicacy, that enables the operator to send the message.

Sir William Thompson's reflecting galvanometer needle is a notable illustration of the perfection to which a galvanometer may be brought; and his original instrument has been surpassed and brought up to a still higher pitch of refinement by Mr. Becker, the learned and obliging head of the instrument department at Messrs. Elliott's. The writer understood him to say that he was making one to show *a resistance of one in a million units.*

Mr. Becker arranged a most excellent series of instruments for demonstrating at the Polytechnic. The Thompson's reflecting galvanometer needle with Wheatstone's bridge are shown above (Fig. 394), as exhibited at the above-named institution by the writer.

The reflecting galvanometer needle must first engage our attention. It consists of two large flat bobbins, B B (Fig. 395), upon which are wound many hundred yards of insulated fine copper wire, and, in the instrument made for the writer, they were placed on hinges, so that they could be placed down, like the lid of a box, to disclose the delicate needle—a small magnet, A, made of watch-spring about an inch long, and weighing only a few grains, and hung by a very narrow piece of tape; because a filament of silk, if made the suspender, would have caused the instrument to be too delicate for lecture-room purposes.

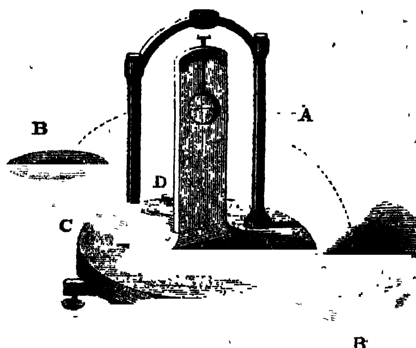


FIG. 395.—*Thompson's Reflecting Galvanometer Needle, with the Bobbins opened to show the suspended Needle.*

Fastened to the little magnet is a circular mirror, ground slightly concave, and weighing only a few grains; upon this is thrown from an aperture in a copper lantern a few rays from the oxy-hydrogen light. These are reflected upon a scale of 5 ft. 6 in. in length, so that the spot of light when it traversed the scale could be seen by an audience of one thousand people.

The movements of the spot of light are, of course, those of the magnet, and in order that the latter should be acted upon only by the currents sent through the instrument, and not by terrestrial magnetism, a curved steel magnet, working up or down or right and left, or a brass rod, is placed above it, and is most convenient for keeping the axis of the little mirror A, with its attached magnet, exactly between and parallel with the two bobbins B B, or, in other words, reflecting the spot of light to zero. C and D represent the connecting screws.

But, perfect as this galvanometer is, it would not have enabled the writer to teach others much about resistances and other interesting points connected with the Atlantic Telegraph cable, unless he had used an instrument for which sufficient credit has not been given to its distinguished inventor, Wheatstone, viz.,

THE DIFFERENTIAL RESISTANCE MEASURER.

This instrument (better known by the name of Wheatstone's Bridge) was also constructed by Mr. Becker on the largest scale (Fig. 394). The board is 8 ft. long and 2 ft. 8 in. wide; the lozenge-shaped brass plates are 1½ in. wide. There are four breaks with binding-screws, and, by using bobbins upon which the B. A. unit of German silver wire was wound, the audience was made to understand that each bobbin represented a mile of pure copper wire, No. 16.

In the lecture-room, the resistance of two miles, as compared with one mile, of wire was clearly demonstrated. The resistance of two equal pieces of wire was shown to be altered by heat, obtained by merely touching one with the hand or putting it into the mouth.

Three tubs of water, containing three lengths of wire, measuring one hundred yards, were supposed to represent the Atlantic Telegraph Cable, and were balanced against a resistance coil. Directly the miniature cable was broken, the spot of light became violently agitated when the key was pressed down; and it was shown that, time permitting, the lecturer could discover not only that the wire *was* broken, but *where* it was broken--just as they can now discover any place thousands of miles from England, and deep down in the bed of the Atlantic Ocean, where an accident may have happened to the cable; they can determine the precise spot, and, by sending a proper vessel with tackle, can pick up and reunite and repair the broken part, as they did in the recovery and resplicing of the old Atlantic Telegraph Cable.

The Differential Resistance Measurer is fully described by Wheatstone in the "Transactions of the Royal Society," 1843, Part II., p. 323.

For the sake of the young student, and considering also that the construction and principle of Wheatstone's bridge frequently form the subject of an examination question, the writer gives the following diagrams and explanations, which he trusts will be found useful.

For the sake of simplicity, the brass bands and breaks only are shown.

The galvanometer is supposed to be resting in the middle of the board, the battery on the right, and the connecting key on the left.

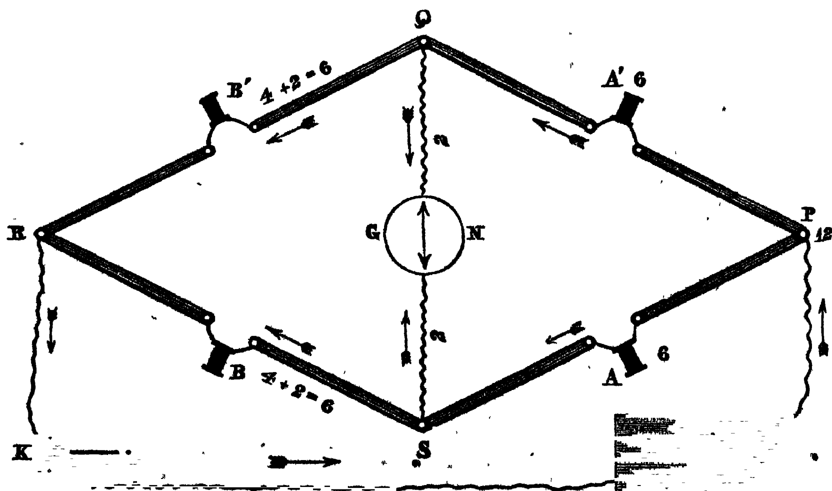


FIG. 396.—DIAGRAM I.

For the sake of discussion, it is supposed that the current coming from the battery, B *a*, is represented by twelve parts: these, on arriving at P, split or divide into equal parts; six go in the direction A′, and six in the other. A.

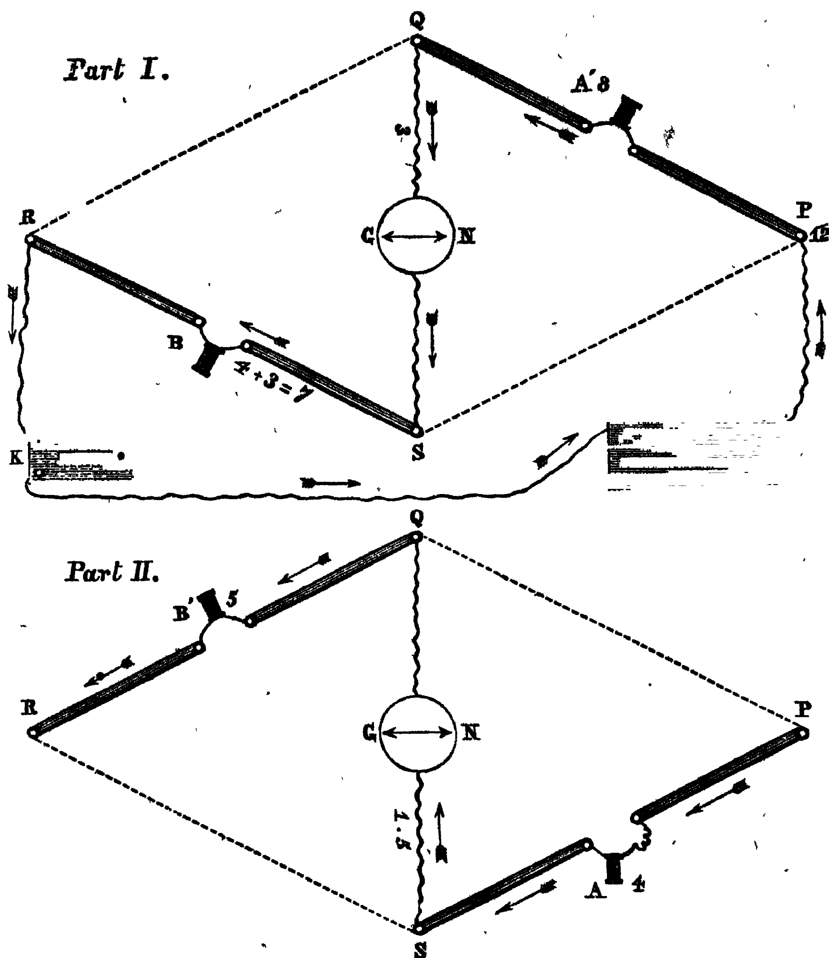


FIG. 397.—DIAGRAM II.

The two currents, represented by arrows, both pass through equal resistance coils, A' A, and the respective currents might pass direct to the key K (where contact is made or broken), and through that to the other pole of the battery; but the currents are partially arrested by the equal resistance coils, B' B, and a portion of the currents is forced into or diverted into the galvanometer, G N.

The use of the coils, or any other resisting matter, on the other side of the galvanometer is to force, or rather gently to impel, a part of the current into the galvanometer; because, if this was not done, the deflection would be so small it might be barely perceptible.

Let us say, for the sake of discussion, that two parts pass to the galvano-

meter from Q, and two parts from S; such currents, coming in opposite directions, must oppose each other's progress through the galvanometer, and therefore the needle of the latter does not move.

We have only now to suppose that $4+2=6$ proceed from Q′ to R, and $4+2=6$ by S to R; the two added together make 12, the original quantity started with, which proceeds through the key and connecting wire to the other pole of the battery, B *a*.

The second diagram (Fig. 397) consists of two parts, viz., Part I. and Part II., and it is recommended that the latter be traced on tracing-paper by the student, who can place it upon Part I. The current again is represented by twelve parts. The resistance of the coil at A′, Part I., being less than A, Part II., the greater part of the current, say 8 A′ parts, go through the former, and 4 A through the latter, consisting of a piece of copper wire and a resistance coil; therefore, returning to Part I., the current going by A′, through Q′, to G N, the galvanometer needle, forms at the point Q′ a greater partial current (say three parts) than the current going by A, Part II., which divides at S, and is represented by, say, one and a half parts; therefore, the current that deflects the galvanometer is the greater current going by Q′, Part I., and marked 3; consequently it amounts in imagination to a struggle between the current going by Q′, Part I., represented by three parts, and the current going by S, Part II., or one and a half parts. The issue cannot be doubtful; the greater current, three, overcomes the lesser, one and a half. In Part I., $4+3=7$ go by B; and in Part II., five go by B; and, if the two are added together, they again make the twelve parts, which, as before, travel through the key and connecting wire to the other pole of the battery, B *a*.

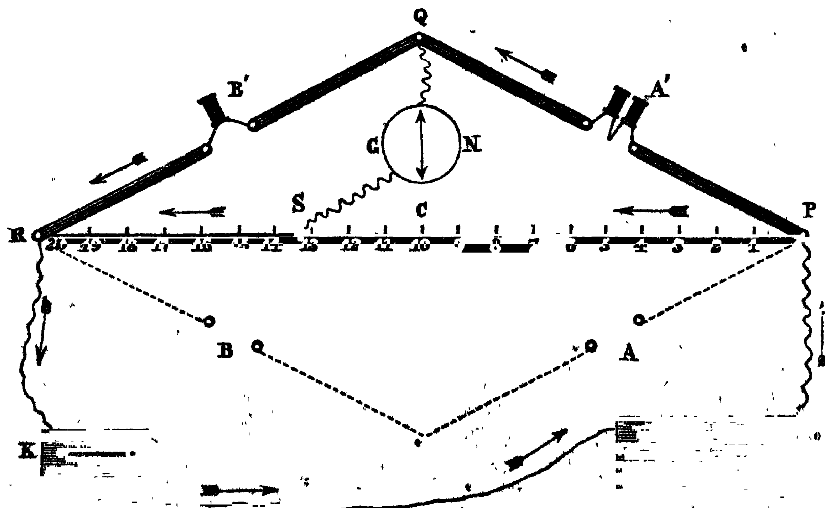


FIG. 398.—DIAGRAM III.

This diagram (Fig. 398) explains the use of the "bridge" for comparing the conductivity or resistance of wires of different metals or different lengths of

the same wire. The lower part, A B, of the bridge, marked in dotted lines, is not required, its place being filled by a long German silver wire stretched from P to R, and provided with a scale divided, say, into twenty parts; on this wire slides a clip or binding-screw, S, and this is connected with one of the galvanometer-screws, the other screw of the galvanometer being connected with Q.

In this case, we are to suppose it is being used to ascertain the relative lengths of wire of the same metal, diameter, and conductivity. The clip, S, has been moved from the centre, C, to No. 13·334 on the scale painted below the wire, P R. The clip has been moved to 13·334, or until the galvanometer is at rest; this quantity, 13·334, is double that of R S, therefore the resistance at B′ is shown to be half the resistance at A′, because A′ has two coils, or two miles of wire, and B′ one mile; so that it is shown, without any previous knowledge of the absolute length of the two coils at A′ (the wire under examination), that it is double the length of the known quantity, one mile at B′, because the scale from R to S is 6·666, and that from P to S 13·334, and, if one is added to the other, they make up the whole scale of 20.

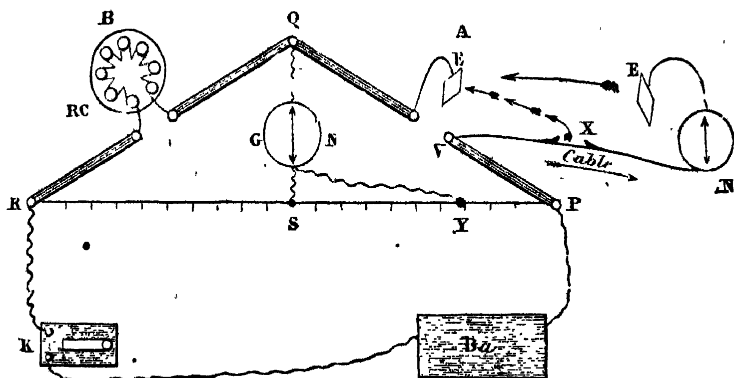


FIG. 399.—DIAGRAM IV.

The object of the diagram (Fig. 399) is to explain the use of the arrangement (Fig. 398, Diagram III.), for the purpose of discovering the exact point under the Atlantic Ocean where the cable is supposed to be broken. As before, the lower part of the bridge is not used: the wire, P R, and scale are employed in this experiment.

The current, starting from the battery B *a*, arrives at P, where it splits into two currents: one passes along the wire, P R, and the other is supposed to go through the cable marked "Cable," at A. The galvanometer needle is brought to rest by the balancing of the resistance of the cable by various resistance coils, R C, at B′: this supposes the cable to be perfect when the clip, S, is in the centre.

Let us now imagine that the cable is broken at X. The spot of light from Thompson's galvanometer needle (see Fig. 394, p. 424) is now violently agitated or deflected when the contact is made with the battery, because the current, instead of travelling through the whole length of the cable, takes a

short cut, as shown by the short arrows; its path or resistance is decreased enormously, and it no longer balances with the resistance coils, R C, at B'. To make it balance, the clip, S, is moved to Y; then by measuring the distance from R to Y, and the distance from P to Y, on the graduated scale, it is easy by a calculation to discover the distance from the shore where the rupture has taken place. V is supposed to be Valentia, and N, Newfoundland; E and E are the wires which go out into the sea, and are usually designated as "earth-plates" in all diagrams, to prevent confusion.

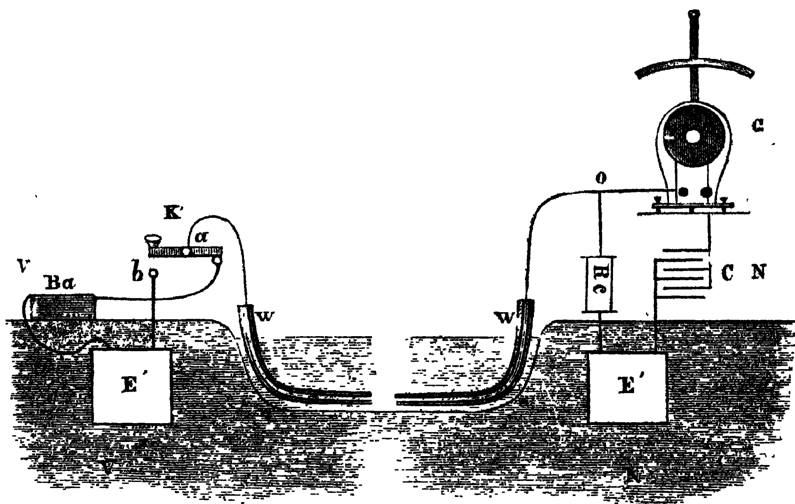


FIG. 400.—DIAGRAM V.

The last diagram (Fig. 400) is intended to give the student a general notion of the apparatus required to send the electric current, *i.e.*, "messages," through the great Atlantic Telegraph cable.

We commence at V, Valentia. B *a* is the battery connected with the earth-plate, E'; K is the key connected with the other pole of the battery at *a;* E' is the earth-plate (not really so, as it is a wire running into the sea); W W represents the cable under the water, passing across to N, Newfoundland, where the electric force enters the condenser, C (an arrangement of mica plates and tin-foil, fulfilling the same office as a Leyden battery), through the galvanometer, G; R *c* is a large resistance coil connected with the earth-plate and also with the cable at the point O: one side of the condenser is also connected with the earth-plate.

The course of the electric force is certainly tortuous, but, once studied and understood, is one of the most simple and beautiful processes of reasoning that the lover of science can desire.

As the cable is now represented in the diagram, a current can pass from the battery, B *a*, through K, at the point *a*, to the cable, and through it to the point O, where the greater part will pass through G, the galvanometer, into the condenser, C; the other part of the current passing from O, through the resistance

coil, R c, to the earth-plate E′, and from E′ back to the battery B a, through the other earth-plate, E′.

The current, in passing through the galvanometer, deflects it until it has fully charged the condenser, when it returns to zero.

The signals are sent by pressing down the key, K, and so putting the cable to earth as the key is pressed down upon b, which is connected with the earth-plate E′. The consequence is that the electrical tension of the cable falls below that of the condenser; a current then flows from the condenser, C, through the galvanometer, G (deflecting it, the deflection being the signal), to the cable, in order to establish the equilibrium of the latter.

At a banquet given, at the Polytechnic, by the chairman and directors of the Royal Polytechnic to Sir Charles Wheatstone and the scientific men of London, at which many noblemen and gentlemen assisted, the writer was enabled, by the kindness of the various telegraphic companies, to bring the wires into the Polytechnic; and, whilst the company were seated, the following message was sent to the President of the United States, and his answer received, as reprinted in "The Evening Post," New York, Wednesday, January 1, 1868:

"CABLE NEWS.—*Advices from Europe to December* 30, 1867.—The following advices by the Atlantic Telegraph have been received:

"INTERNATIONAL COURTESIES.

"*London, December* 24.—At a banquet given at the Royal Polytechnic on Saturday night last, in reply to the following sentiment from the Duke of Wellington and Sir Charles Wheatstone, a despatch from the President of the United States was read amid great enthusiasm. Not a little of the interest attaching to these despatches grows out of their rapid transmission:

"MESSAGE OF THE DUKE OF WELLINGTON TO THE PRESIDENT OF THE UNITED STATES.

"'*Royal Polytechnic, London, December* 21.—The Duke of Wellington, the directors and scientific guests now at the Royal Polytechnic, London, England, send their most respectful greeting to the President of the United States, their apology being that to the discoveries of science the intercourse between two great nations is indebted.'

"[The above message was 9 minutes 30 seconds in transit from London to Washington, as follows: London to Heart's Content, 4 minutes 30 seconds; Heart's Content to Plaister Cove, 1 minute 30 seconds; at Plaister Cove, 30 seconds; Plaister Cove to New York, 1 minute 30 seconds; New York to Washington, 1 minute 30 seconds.]

"REPLY.

"'*Washington, December* 21.

"'*Duke of Wellington, London:* I reciprocate the friendly salutation of the banqueting party at the Royal Polytechnic, and cordially agree with them in the sentiment that free and quick communication between governments and nations is an important agent in preserving peace and good understanding throughout the world, and advancing all the interests of civilization.

"'ANDREW JOHNSON.'

"The reply occupied 29 minutes in actual transmission. On the same evening, a message of twenty-two words was started from the Polytechnic for Heart's Content at exactly 9 p.m., and at 9.10 the reply of twenty-four words was delivered."

The completion of the articles on LIGHT, HEAT, ELECTRICITY, and MAGNETISM, &c., cannot be better consummated than by a report, which appeared in the "Literary Gazette," of Faraday's lecture at the Royal Institution,

ON THE CONSERVATION OF FORCE.

"When we occupy ourselves with the dual forms of power, electricity and magnetism, we find great latitude of assumption: and necessarily so, for the powers become more and more complicated in their conditions. But still there is no apparent desire to let loose the force of the principle of conservation, even in those cases where the appearance and disappearance of force may seem most evident and striking. Electricity appears when there is consumption of no other force than that required for friction; we do not know how, but we search to know, not being willing to admit that the electric force can arise out of nothing. The two electricities are developed in equal proportions; and, having appeared, we may dispose variously of the influence of one upon successive portions of the other, causing many changes in relation, yet never able to make the sum of the force of one kind in the least degree exceed, or come short of, the sum of the other. In that necessity of equality we see another direct proof of the conservation of force in the midst of a thousand changes that require to be developed in their principles before we can consider this part of science as even moderately known to us. One assumption with regard to electricity is, that there is an electric fluid rendered evident by excitement in plus and minus proportions. Another assumption is, that there are two fluids of electricity, each particle of each repelling all particles like itself, and attracting all particles of the other kind always, and with a force proportionate to the inverse square of the distance, being so far analogous to the definition of gravity. This hypothesis is antagonistic to the law of the conservation of force, and open to all the objections that have been, or may be, made against the ordinary definition of gravity. Another assumption is, that each particle of the two electricities has a given amount of power, and can only attract contrary particles with the sum of that amount, acting upon each of two with only half the power it could, in like circumstances, exert upon one. But various as are the assumptions, the conservation of force, though wanting in the second, is, I think, intended to be included in all. I might repeat the same observations nearly in regard to magnetism,—whether it be assumed as a fluid or two fluids or electric currents—whether the external action be supposed to be action at a distance or dependent on an external condition and lines of force—still all are intended to admit the conservation of power as a principle to which the phenomena are subject. The principles of physical knowledge are now so far developed as to enable us not merely to define or describe the *known*, but to state reasonable expectations regarding the *unknown;* and I think the principle of the conservation of force may greatly aid experimental philosophers in that duty to science which consists in the enunciation of problems to be solved: It will lead us, in any case where the force remaining unchanged in form is altered in direction only, to look for the new disposition of the force, as in the cases of magnetism, static electricity, and perhaps gravity, and to ascertain that as a whole it remains unchanged in amount; or, if the original force disappear, either altogether or in part, it will lead us to look for the new condition or form of force which should result, and to develop its equivalency to the force that has disappeared. Likewise, when force is developed, it will cause us to consider the previously

existing equivalent to the force so appearing; and many such cases there are in chemical action. When force disappears, as in the electric or magnetic induction after more or less discharge, or that of gravity with an increasing distance, it will suggest a research as to whether the equivalent change is one within the apparently acting bodies or one *external* (in part) to them. It will also raise up inquiry as to the nature of the internal or external state, both before the change and after. If supposed to be external, it will suggest the necessity of a physical process, by which the power is communicated from body to body; and in the case of external action, will lead to the inquiry whether, in any case, there can be truly action at a distance, or whether the ether, or some other medium, is not necessarily present. We are not permitted as yet to see the nature of the source of physical power, but we are allowed to see much of the consistency existing amongst the various forms in which it is presented to us. Thus if, in static electricity, we consider an act of induction, we can perceive the consistency of all other like acts of induction with it. If we then take an electric current, and compare it with this inductive effect, we see their relation and consistency. In the same manner we have arrived at a knowledge of the consistency of magnetism with electricity, and also of chemical action and of heat with all the former; and if we see not the consistency between gravitation with any of these forms of force, I am strongly of the mind that it is because of our ignorance only. How imperfect would our idea of an electric current now be if we were to leave out of sight its origin, its static and dynamic induction, its magnetic influence, its chemical and heating effects? or our idea of any one of these results, if we left any of the others unregarded? That there should be a power of gravitation existing by itself, having *no relation to the other natural powers, and no respect to the law of the conservation of force*, is as little likely as that there should be a principle of levity as well as of gravity. Gravity may be only the residual part of the other forces of nature, as Mossotti has tried to show; but that it should fall out from the law of all other force, and should be outside the reach either of further experiment or philosophical conclusions, is not probable. So we must strive to learn more of this outstanding power, and endeavour to avoid any definition of it which is incompatible with the principles of force generally, for all the phenomena of nature lead us to believe that the great and governing law is one. I would much rather incline to believe that bodies affecting each other by gravitation act by lines of force of definite amount (somewhat in the manner of magnetic or electric induction, though without polarity), or by an ether pervading all parts of space, than admit that the conservation of force can be dispensed with. It may be supposed that one who has little or no mathematical knowledge should hardly assume a right to judge of the generality and force of a principle such as that which forms the subject of these remarks. My apology is this: I do not perceive that a mathematical mind, simply as such, has any advantage over an equally acute mind not mathematical in perceiving the nature and power of a natural principle of action. It cannot of itself introduce the knowledge of any new principle. Dealing with any and every amount of static electricity, the mathematical mind can and has balanced and adjusted them with wonderful advantage, and has foretold results which the experimentalist can do no more than verify. But it could not discover dynamic electricity, nor electro-magnetism, nor magneto-electricity, nor even suggest them; though, when once discovered by the experimentalist, it can take them up with extreme facility. So in respect

of the force of gravitation, it has calculated the results of the power in such a wonderful manner as to trace the known planets through their courses and perturbations, and in so doing has *discovered* a planet before unknown; but there may be results of the gravitating force of other kinds than attraction inversely as the square of the distance, of which it knows nothing, can discover nothing, and can neither assert nor deny their possibility or occurrence. Under these circumstances, a principle, which may be accepted as equally strict with mathematical knowledge, comprehensible without it, applicable by all in their philosophical logic, whatever form that may take, and, above all, suggestive, encouraging, and instructive to the mind of the experimentalist, should be the more earnestly employed and the more frequently resorted to when we are labouring either to discover new regions of science, or to map out and develop those which are known into one harmonious whole; and if in such strivings we, whilst applying the principle of conservation, see but imperfectly, still we should endeavour to see, for even an obscure and distorted vision is better than none. Let us, if we can, discover a new thing in *any shape;* the true appearance and character will be easily developed afterwards. Some are much surprised that I should, as they think, venture to oppose the conclusions of Newton: but here there is a mistake. I do not oppose Newton on any point; it is rather those who sustain the idea of action at a distance that contradict him. Doubtful as I ought to be of myself, I am certainly very glad to feel that my convictions are in accordance with his conclusions. At the same time, those who occupy themselves with such matters ought not to depend altogether upon authority, but should find reason within themselves, after careful thought and consideration, to use, and abide by, their own judgment. Newton himself, whilst referring to those who were judging his views, speaks of such as are competent to form an opinion in such matters, and makes a strong distinction between them and those who were incompetent for the case. But, after all, the principle of the conservation of force may by some be denied. Well, then, if it be unfounded even in its application to the smallest part of the science of force, the proof must be within our reach, for all physical science is so. In that case, discoveries as large or larger than any yet made may be anticipated. I do not resist the search for them, for no one can do harm, but only good, who works with an earnest and truthful spirit in such a direction. But let us not admit the destruction or creation of force without clear and constant proof. Just as the chemist owes all the perfection of his science to his dependence on the certainty of gravitation applied by the balance, so may the physical philosopher expect to find the greatest security and the utmost aid in the principle of the conservation of force. All that we have that is good and safe, as the steam-engine, the electric telegraph, &c., witness to that principle,—it would require a perpetual motion, a fire without heat, heat without a source, action without reaction, cause without effect, or effect without a cause, to displace it from its rank as a law of nature."

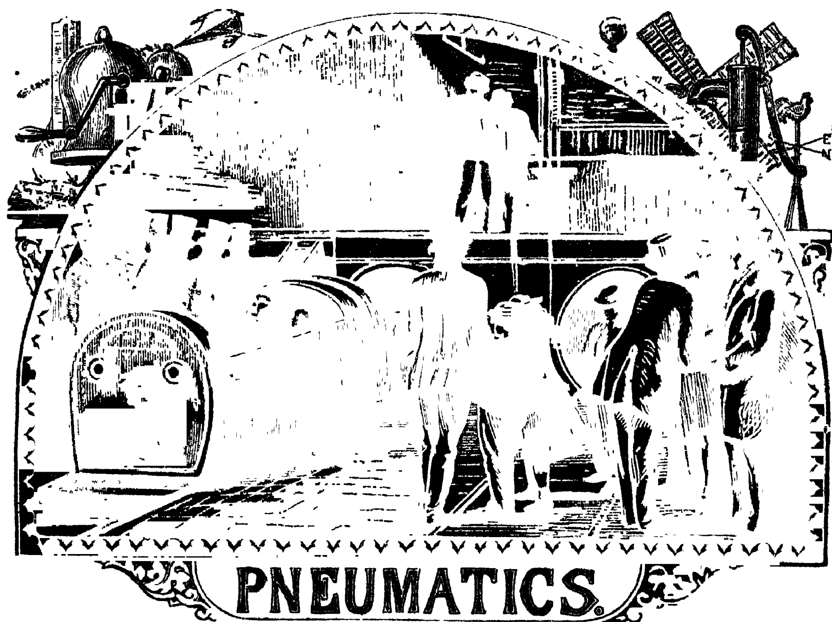


FIG. 401.—*The Pneumatic Despatch Company's Tube.*

PNEUMATICS.

UNDER the streets! What a curious but indispensable series of utilities is to be found beneath the stony ways of this vast city! To-day our cabs cannot make way because the streets are up for the new water-pipes; to-morrow it is gas; many months ago it was sewage; and further back it was the tubes of the Pneumatic Despatch Company. Air made the slave of man! Air, which generally wafts the aëronaut on such a wild and doubtful path, is here enchained, and made to behave itself. The air cannot blow the parcels hither and thither, like the gossamer of the school-boys—the supposed herald, in youthful days, of a cake; but work it must, in one direction or the other, by the iron will of man, through another power, the steam-engine, moving a very important instrument called the "Blower."

Hippocrates expressed the deep-drawn inspiration by Πνευμα; and it may be supposed that, in consideration of the labour required to work an air-pump, particularly one of the old days, they agreed to call the experiment "pneumatic," and to class the whole series of facts under one common title of Pneumatics. Be this as it may, they styled the latter the sister of Hydrostatics, and considered both to be a branch of Mechanics.

The learned Boerhaave considered air (the matter surrounding our terraqueous globe) as "a universal chaos or colluvies of all kinds of created bodies, besides the matter of light or fire which continually flows into it from the

heavenly bodies, and probably the *magnetic effluvia* of the earth: whatever fire can volatilize is found in the air."

Aristotle, reviewing the four ancient elements, says they all have weight, fire excepted; and he adds, that a bladder full of air weighs more than when it is quite empty.

It is the closed bladder that proves, on pressure, that air fills space, to the exclusion of other matter, until it is removed; that, in fact, air has the property conveniently expressed by the term "impenetrability." The bellows corked, a bladder full of air, and well secured at the orifice with waxed string, an umbrella turned inside out by the force of air, the wind, demonstrate, in a simple but conclusive manner, the materiality of that which philosophers prefer to estimate as a mechanical agent with the assistance of the air-pump.

Sprengel's air-pump is the prettiest and most simple arrangement for certain experiments which it is not necessary to conduct on the large scale. This pump (if it may be so called) will be explained presently. As a contrast to it, we have the powerful and useful pump of Mr. C. W. Siemins, now made by the good successor to Knight, of Foster Lane, City, viz., Mr. James Howe. The inventor's pump is thus described:

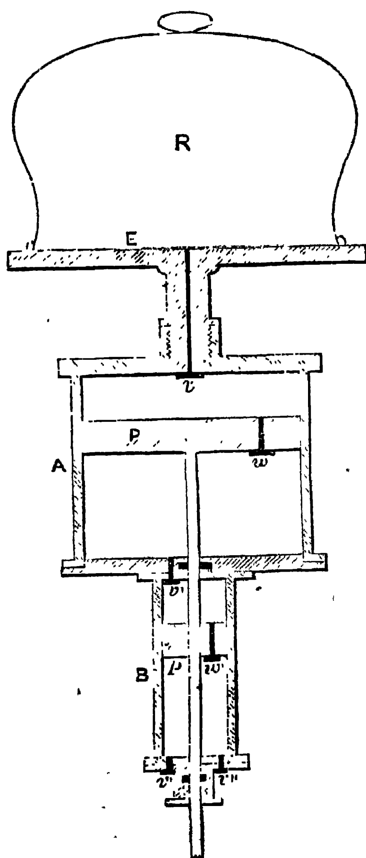


FIG. 402.

"The Siemins air-pump consists of two cylinders, differing in magnitude, of which the smaller is applied either to the bottom or top of the larger, while the valved pistons belonging to each respectively are attached to the same piston-rod. The air withdrawn from the receiver, or other vessel intended to be exhausted, is condensed in the lower cylinder into one-fourth part of its original volume, and consequently always possesses sufficient elasticity to pass through the discharging valve and escape into the atmosphere, the opposing pressure of which on that valve is thus counteracted in a manner perfectly novel.

"The following are the parts of which this instrument consists, as shown in the annexed sectional view (Fig. 402):

"The exhausting cylinder, A. A second cylinder, B, equal in length to the first, to the bottom of which (in the form of the instrument here represented) it is fixed, but having only one-third or one-fourth of its sectional area, and only one-third or one-fourth, therefore, of its cubical contents.

"The cylinders are separated by a

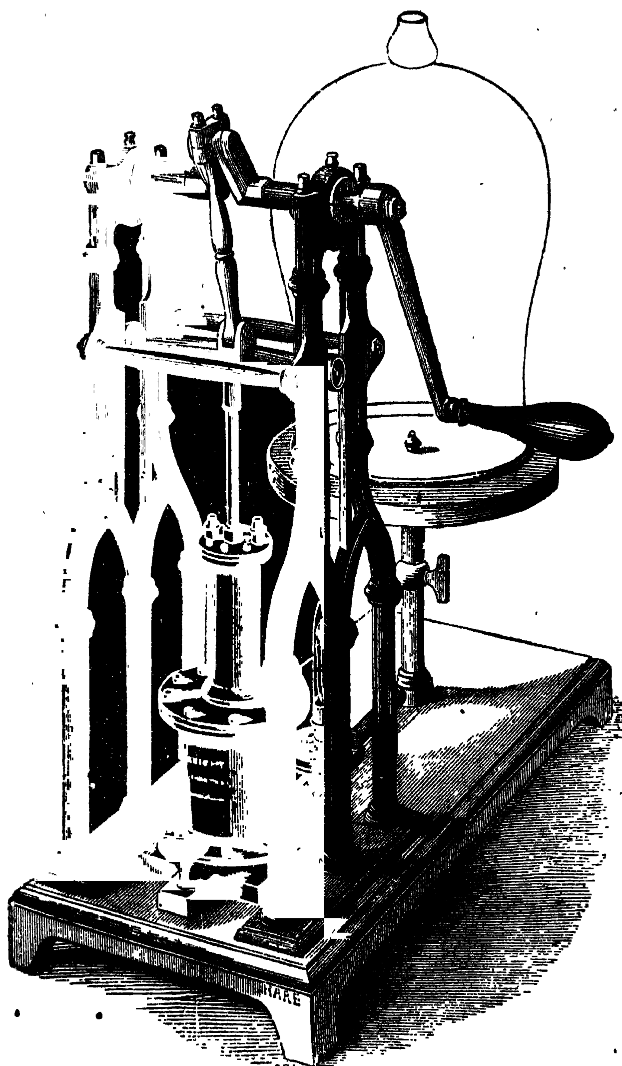


FIG. 403.

plate forming at once the bottom of the upper and the top of the lower cylinder, the only air-passage between them being a silk valve, *v'*.

"In each cylinder works a valved piston, P, and *p*, attached to a piston-rod common to both, which passes through a stuffing-box in the plate. The distance between the pistons is such that, when P is in contact with the top of the upper or exhausting cylinder, *p* is in contact with the top of the small or lower cylinder; and when P is in contact with the bottom of the large cylinder, *p* is in contact with that of the small cylinder. The pump-plate, E, placed above the large cylinder A, supports the receiver R, or other vessel to be exhausted, from which the air flows through the valve *v*, during the descent of the piston P.

"Fig. 403 represents the complete pump, as manufactured for philosophical purposes. The motion of the pistons is effected by means of a short crank with a jointed connecting-rod, converting the circular motion given by the lever handle into a vertical one, which is maintained by means of a cross-head, with rollers working between guides.

"The action of this air-pump is as follows:

"On the descent of the piston P, tending to produce a vacuum in the exhausting cylinder, A, by causing a difference of pressure above and below the first valve, *v*, in the top of the cylinder, the elasticity of the air in the receiver causes it to pass through the valve *v*. The air below the piston, P, is at the same time pressed through the valve, *v′*, in the plate separating the cylinders, and enters the cylinder, B, in which a vacancy is simultaneously made for it by the descent of the piston *p*; and, in consequence of the difference of capacity of the two cylinders, it becomes reduced to one-fourth of its original bulk, its elasticity, according to the well-known law, being proportionally increased. The air contained in the small cylinder below the piston, *p*, will, in like manner, be pressed through the valves, *v*, *v″*, into the atmosphere.

"During the ascent of the pistons, the valves, *v*, *v′*, *v″*, will be closed, and the valves, *w*, *w′*, in the pistons opened by the upward pressure of the air in the cylinders and atmosphere, admitting the air in each cylinder to pass through the pistons as they rise, in order that, in the following downward movement, the air, which during the previous stroke of the pump issued from the receiver into the exhausting cylinder, may be withdrawn from that into the lower cylinder, while the air condensed in the latter may be finally expelled into the atmosphere. By this construction of the instrument we are enabled to obtain a more perfect vacuum than by any air-pump previously devised.

"In order to prove this, let us compare the action of two air-pumps, one of the improved, the other of the usual construction, assuming that they are equally perfect in workmanship. If an air-pump could discharge the entire quantity of air contained in it at the end of every stroke of the piston, and if the action of the valves were also perfect, there would be nothing to prevent our obtaining a perfect vacuum.* But whoever has tried the experiment will have found that an ordinary philosophical air-pump does not remove much

* The inventor of the new air-pump makes the following remarks on this subject:—"It is the opinion of some natural philosophers that the whole of the air could never be exhausted from a closed vessel by means of a pump, even if the apparatus were theoretically perfect. From that opinion, however, I must beg leave to dissent; for, even if the repulsive force which separates the atoms of fluids were itself unlimited (which, however, has never been proved), there necessarily must be a limit where that force and the force of gravity acting on a single particle just equal each other; and if a vessel were emptied of air to this extent, and a further portion were withdrawn, the remainder would no longer be able to fill the whole vessel, but would cover the bottom only, as a non-elastic fluid would, leaving a perfect vacuum above. In this state of things, continual withdrawals of air from the lower part of the vessel would at length cause the last atom itself to be withdrawn."

more than $\frac{99}{100}$ of the atmosphere from the receiver, however long he may have continued to work the instrument. We may conclude, therefore, even when the piston is in contact with the bottom of the cylinder, that there still remains a space equal to $\frac{1}{100}$ of the capacity of the cylinder, through which the piston cannot be depressed, and where the air is merely condensed, expanding and refilling the whole cylinder when the piston is raised.

"Now, let us suppose that in the new air-pump the piston, P, leaves $\frac{1}{100}$ of the air in the exhausting cylinder, A, undisplaced, and that the piston, *p*, cannot be brought within $\frac{1}{100}$ part of the length of stroke of the top or bottom of the smaller cylinder, the working having been continued until no further exhaustion is effected. At this period, the piston, *p*, will leave in the cylinder, B, during the downward stroke, $\frac{1}{100}$ of its bulk of air of the atmospheric density unexhausted: if it be raised again, this portion of air will expand and fill the cylinder, B, with air, the density of which will be only $\frac{1}{100}$ that of the atmosphere. The piston, P, will at the same time ascend to the top of the exhausting cylinder, A, filled with air of the same density as that remaining in the receiver; but, the exhaustion having reached its utmost limit, during the next downward stroke no air will be discharged from cylinder A into cylinder B: the air above the piston in the latter will, at the termination of this stroke, have expanded 100 times, and, having previously expanded to an equal amount during the upward stroke, it will now be reduced to the density $\frac{1}{10000}$ that of the atmosphere. If no force were required to open the valve, v', air would, in this state of things, pass from the upper into the lower cylinder, unless that in the former, 100 times compressed as it would be at the end of the downward stroke, were not still rarefied 10,000 times, or—what is the same thing—if it were not, when it filled the cylinder A, 1,000,000 times rarefied. We find, therefore, that by the addition of the second cylinder the vacuum may be rendered 10,000 times more perfect than if the cylinder A had been employed alone in the manner of an air-pump.*

"As the leakage of the valves and piston is a principal cause of the imperfection of the vacuum obtained by means of air-pumps of the ordinary construction, it may be objected that, as we have in the new one two valves and one piston more than usual, the loss of effect from this cause will be proportionally greater. This, however, is not the case. On the contrary, the loss from leakage at the valves and pistons is diminished in the new air-pump nearly in the same ratio as the opposing unexhausted space in the cylinder. The amount of leakage through a given aperture bears a certain proportion to the difference of pressure on each side (increasing as the square root of the pressure); and it will be observed that this difference of pressure, especially in the large cylinder, is very small indeed, and occurs at intervals only, whereas, in the case of an ordinary single-acting pump, the entire atmosphere constantly rests on the piston and exhausting-valve. Besides, in the new air-pump the leakage of the air through the apparatus is opposed by a greater number of obstructions, one after another, between the discharging-valve and the re-

* *Cæteris paribus*, if a well-made pump, of any of the ordinary forms, will rarefy the air to $\frac{99}{100}$, the new one would carry the rarefaction up to $\frac{999,999}{1,000,000}$, if the valve, v', could be rendered automatic.

ceiver. Indeed, the efficacy of the pump would not be impaired in any considerable degree if even the valve, *v*, were removed altogether, and any one of the others should be in a very leaky state.

"Another circumstance interfering with the power of obtaining a good vacuum by means of a well-made air-pump of any of the forms previously constructed, but which is obviated in the instrument now described, is, that the valve through which the air has to pass from the receiver into the pump is forced into its seat at the end of the reversed stroke by the whole pressure of the atmosphere, *minus* only that of the air remaining in the receiver. By this the silk valve is soon injured, and, what is even more important, the rarefied air has not power to force it open again, and the exhaustion consequently ceases before the vacuum has attained that degree of perfection to which it might otherwise be carried. One of the most obvious objections to an ordinary air-pump, whether single or double acting, arises from the inequality of the force required to move the piston through different portions of the stroke, and from the very great force which is ultimately requisite.

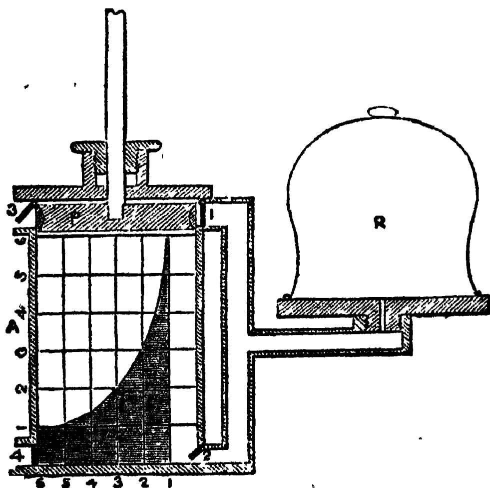


FIG. 404.

"In the diagram (Fig. 404), A is the barrel of a double-acting air-pump which, by the alternate motion of the piston, P, and the valves 1, 2, 3, and 4, produces a partial vacuum in the receiver or closed vessel, R. Let us suppose that five-sixths of the air originally contained in R have been removed, and that the working of the pump is still continued. The resistance which the piston will now have to encounter is readily found from the law of Mariotte, and will be represented by the shaded part of the diagram, bounded by the parabolic curve. At the commencement of the stroke, the pressure on both sides of the piston being equal to one-sixth atmosphere, the resistance is 0; it increases gradually in proportion to the diminution of the space below the piston, until the air has been compressed to one-sixth of its original volume, when

its density will have become equal to that of the atmosphere, and the discharging-valve, **4**, will be opened. It is evident, in this case, that the force required to move the piston to the bottom of the cylinder must be sufficient to overcome the *maximum* resistance, which will be about $3\frac{1}{4}$ times greater than the average amount that would be experienced if the entire resistance could be distributed over the whole stroke.

"In this illustration we have supposed the pump to be double acting, and have, therefore, deducted from the actual pressure against the piston the uniform 'aiding pressure' of the air which follows it freely from the receiver through the valve, **1**.

"Air-pumps for philosophical purposes are very commonly single acting, the pressure of the atmosphere being constantly exerted on one side of the piston only; but when there are two cylinders, as is frequently the case, having their piston-rods connected with the opposite ends of the same lever, the atmospheric pressure on one piston balances that on the other, and the resistance will be equivalent to that occurring in a pump with one double-acting cylinder. In a single-barrel pump with open top the inequality of load is still greater than in a double-acting or double-cylinder pump. The inequality of load increases as the rarefaction proceeds, but the resultant of the resistance attains its maximum when the vacuum equals 19 in. of mercury in the gauge, or when nearly two-thirds of the atmosphere have been removed from the receiver, after which it constantly diminishes.

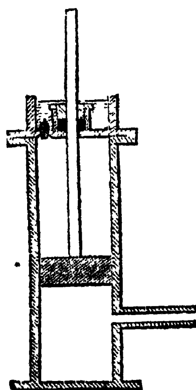


FIG. 405.

"It will readily be perceived that in the improved air-pump this great inequality of load does not exist, and therefore a pump of several times greater capacity than any given one on the ordinary construction may be worked with equal facility and speed, because the resisting pressure against the larger piston, P, cannot rise at the termination of the stroke to more than four times the pressure of the air still contained in the receiver, and therefore *diminishes* as the perfection of the vacuum increases; and even of this greatest resisting pressure, one-fourth part is balanced by the pressure, on the top of the piston, of the air entering the cylinder from the receiver, and another fourth by the increasing 'aiding pressure' on the top of the small piston, *p*; and the re-

maining half, after a tolerable vacuum has been formed, may be almost entirely neglected. The greatest resistance to the action of the small piston is that of the atmosphere, and is equal, therefore, to the greatest resistance in an ordinary air-pump; but it must be recollected that its area is only one-fourth of the area of the exhausting cylinder.

"One modification, however, of the single-barrel pump is in a great degree free from the objections which have been urged above (see Fig. 405). In it the atmosphere is entirely excluded, the piston in its motion passing an opening through which the air issues from the receiver, and is then discharged by a valve into a vessel filled with oil. Pumps of this construction can be rendered very perfect, but they are liable to grave practical objections, though of a different nature from those applying to the forms previously described. They require more power for working than any other kind of air-pump, because the air which follows the piston in its upward course has to be impelled backward bodily into the receiver, until it again passes the aperture, when it returns to fill the cylinder. Another objection to its general use arises from the circumstance that it requires to be moved slowly, and to receive much attention during the working.

"By the double-cylinder air-pump now submitted to the public a very perfect vacuum may be obtained, even if the stroke is short and the pistons do not touch the bottoms of the cylinders; considerable practical advantage is also realized by the application of a crank to give motion to the pistons. To this may be added the consequent greater ease and speed of working, attended with less *racking* of the entire apparatus, and less injury to the valves, than in any form of air-pump previously constructed.

"Finally, as to the cost, if the perfection of the instrument be taken into consideration, a great saving will be obtained.

"The manufacturers have taken considerable pains to reduce the cost as far as possible: this has been the principal cause of delay in bringing this air-pump before the public; and they are prepared to supply the patent air-pump of the form represented in Fig. 403, the lower or exhausting cylinder of which is 3 in. in diameter, for £21."

We now pass to the description of Sprengel's apparatus (Fig. 406).

The next drawing shows the manner in which the stout glass tube, viz., a barometer tube, is bent. On the centre of the third bend, B (counting from the funnel A), a perpendicular short tube rises, with which any vessel—say a tube required for Geissler's or Gassiott's experiments—with exhausted tubes is attached.

Into the funnel, A, mercury is poured, and as the level of A is higher than that of B, a time arrives when all parts of the bent tube are filled with the mercury, and it begins to flow over the last tube from B to C, and to fall into the trough D, where, to prove the dragging and adhesive power of mercury for air, and to show that every drop of mercury that falls carries with it a proportionate quantity of air, the last tube, B C, is curved at the end, and passes under a tube filled with mercury, and standing on the shelf of the little mercurial trough D. The result of the fall of the mercury from B to C is most decided, and, as the quicksilver may be continually baled out of the trough and poured into the funnel, the process of exhaustion is endless. The proof that air is dragged out of the tube G under exhaustion is shown in the tube T, which indicates, if graduated, the nearly exact quantity of air originally contained in the Geissler tube, G, now deprived of air.

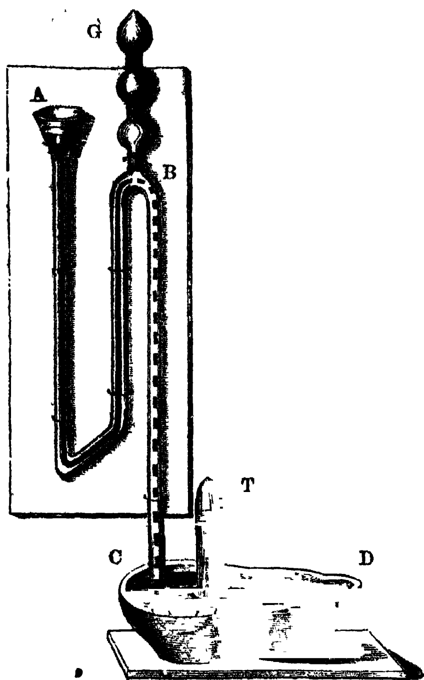


FIG. 406.—*Sprengel's Air-pump.*

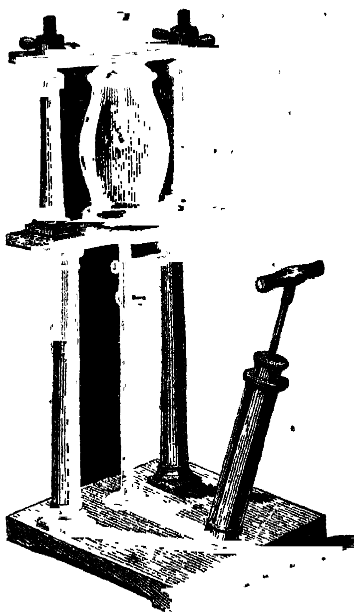


FIG. 407.—*A Condensing Pump.*

The two air-pumps are a great contrast to each other: the first (Siemins's) is intended for work on the large scale; the second (Sprengel's) will do all that a worker in tube-chemistry could desire.

The object of an air-pump is to show the common properties (physical) of air, and, these being understood, it is also of great use in a variety of other philosophical experiments.

The pumps already explained are exhausting pumps; but the same principles, reversed, afford an illustration of a condensing pump, such as the one shown at Fig. 407.

Here a very thick and strong glass receiver is held tightly down with a cross-bar and screws, and by a reversed action of the valves the air is pumped into, but not out of, the vessel.

The condensing air-pump is of great use in supplying air to a diver.

A living diver is soon provided, in the shape of a mouse; this animal is enclosed in a glass jar, open at the bottom, and provided with a stage, on which the little creature may stand without fear of wetting his delicate toes, and, what is of paramount importance (at least to the animal), the jar is continually supplied with fresh air. The air is pumped down to the miniature diving-bell (Fig. 408), and escapes in bubbles at the side.

At the Polytechnic, since its incorporation by royal charter in the year 1838,

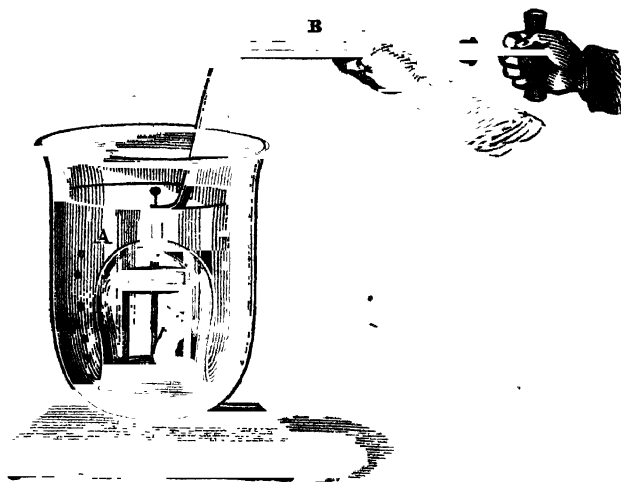


FIG. 408.—*The Mouse under Water.*

The mouse in a bell-jar, A, connected by a flexible pipe with the pump, B.

two 8-inch cylinder air-pumps have supplied the diving-bell with air, which the present chairman, the Rev. J. B. Owen, wittily spoke of as "tolling the knell of each departing shilling," the price of admission to the descending diving-bell.

To illustrate the principle of this machine, take a glass tumbler, plunge it into water with the mouth downwards; you will find that very little water will rise into the tumbler, which will be evident if you lay a piece of cork upon the surface of the water and put the tumbler over it; for you will see that, though the cork should be carried far below the surface, yet its upper side is not wetted, the air which was in the tumbler having prevented the entrance of the water; but as the air is compressible, it cannot, when condensed, entirely exclude the fluid.

The first diving-bell of any note was made by Dr. Halley, and is most commonly seen in the form of a truncated cone, the smallest end being closed, and the larger one open. It is weighted with lead, and so suspended that it may sink full of air, with its open base downwards, and as near as may be parallel to the horizon, so as to be close with the surface of the water. Mr. Smeaton's diving-bell was a square chest of cast iron, 4½ ft. in height, 4½ ft. in length, and 3 ft. wide, and affording room for two men to work in it. It was supplied with fresh air by a forcing-pump. This was used with great success at Ramsgate. Other contrivances have been used for diving-bells.

The first diving-bell we read of in Europe was tried at Cadiz, by two Greeks, in the presence of Charles V. and ten thousand spectators. It resembled a large kettle inverted. The first person who brought the diving-bell into vogue with us was Phipps, an American blacksmith, in the reign of Charles II., and who, from the fortune he acquired from a Spanish ship, to which he went down, laid the foundation of the honours of the Mulgrave family.

The diving-bell in the Great Hall at the Polytechnic is composed of cast iron, open at the bottom, with seats around, and is of the weight of three tons; the interior, for the divers, is lighted by openings in the crown of thick plate glass, which are firmly secured by brass frames screwed to the bell; it is suspended by a massive chain to a large swing crane, with a powerful crab, the windlass of which is grooved spirally, and the chain passes four times over it into a well beneath, to which chain is suspended the compensation weights; and it is so accurately arranged that the weight of the bell is at all depths counterpoised by the weights acting upon the spiral shaft. The bell is supplied with air from two powerful air-pumps, of 8-inch cylinder, conveyed by the leather hose to any depth. The bell is put into action several times daily; and visitors may safely descend a considerable depth into the tank, which, with the canals, holds nearly ten thousand gallons of water, and which can, if required, be emptied in less than one minute.

Messrs. Heinke's diving-helmet and diving-dress have been in use at the Polytechnic for many years, and have been lectured on over and over again. Perhaps the best account of hese lectures and other new facts is that given by the "Builder's" Weekly Reporter:

"The requirements in diving apparatus are a good and regular supply of air, ability to see clearly, freedom of action and from too great pressure of the incumbent water, proper weighting of the diver, dryness without unpleasant tightness of apparel, non-liability to disarrangement in the machinery, facilities to find your way back to the ship's communication, a perfect code of signals, and independent air provision for some time in case of accident to the air-hose. The Messrs. Heinke, submarine engineers, of 79 Great Portland Street, W., have made it a life-long study to improve in every way the dresses and other apparatus required in under-water labour, and have eminently succeeded in their aim. Passing thoughtfully by Borelli's flotatory, submarine, and condensing apparatus, Halley's truncated wooden cone, Rowe's diving-engine, Bushnell's tortoise-shell contrivance, Martin's similar development, &c., this eminent firm has narrowly watched and estimated the defects in each, duly correcting them. The submarine dress manufactured and exhibited at the Great Exhibition in Hyde Park, in 1851, obtained the award of a prize medal; and since that period other improvements have been effected, as their want was made known, the Heinke apparatus being now considered almost perfect; indeed, in its use, danger to life, or even distress of feeling, is rarely experienced by divers in the possession of ordinary health. Among the most prominent of the improvements is that of the eye-frame, to which is attached a brass slide, so contrived that, in case of accident to the glass, the diver can immediately close the eye-hole, and thus save himself from drowning—an event that has more than once happened where Messrs. Heinke's contrivance was absent. Submersion or ascension to any degree is also rendered attainable at will by the introduction of a double valve in the front of the gorget: the weight of the whole apparatus thus raised being upwards of 200 lb. The great feature of all these improvements is that they place the apparatus under the control of the diver, who surely must be the best judge of his own needs and feelings. Thus, in the event of unforeseen casualty, say to the air-hose, there is provision made for a few minutes' supply, as a reserve, before the consumption of which the diver will have had ample time to reach the surface. But the chances of accident to the ordinary hose-screw have been lessened by the application of a double safety-cap, which it is almost impossible to break. This plan

renders the valve at the back of the helmet less indispensable, making the helmet a 'loose' one for many purposes. The connecting joints of the apparatus are also of first-class material and manufacture. These are very important parts of the whole, for great strength, yet ease of removal, is here needed in the face of every adverse condition. Messrs. Heinke fit all their joints, as the hose-screw, with double safety-caps, and make them resist the most powerful pressure. Their new vulcanized band completely excludes the water from the dress, and enables it to fit more easily, and with greater comfort to the wearer. In cold weather the leather band used formerly became hard, and could not be depended on; while the vulcanized band is totally unaffected by atmospheric change or ordinary variations of temperature. Their signal-dial is a most simple yet perfect arrangement, by which the wants of the diver are instantly and correctly made known to those on the attendant vessel. Thus, much time will be saved in the execution of the more important and massive undertakings. Of course, a diver prefers to maintain his equilibrium either under the water or on the land; but this luxury could not always be indulged in under former arrangements. The old helmet and spencer were merely tied round the waist, and the water frequently got in; whereas, with Messrs. Heinke's improved vulcanized band, the diver may turn a complete somersault, and yet the water not get beneath his dress. The front valve in the helmet (before referred to) is very important in its consequences, as it enables the diver to regulate the escape of air and his speed of ascent to the surface. With the escape-valve behind only, the diver was dependent on the apparatus: if that worked badly, or the air-pumps were laboured too fast, and the escape-valve behind let the air out too slowly, the dress might get puffed out, and, like pride, receive a shock at the moment of triumph,—the diver's heels becoming lighter than his head, and his entire body more buoyant than the water, so rising to its surface heels uppermost! This cannot occur with the use of the front valve. The diving-pump will throw water and air at the same time through distinct hose, the air-chamber being divided or separated at will. By this means, the diving-pump can be used for extinguishing fire in ships or other confined places. The diver being supplied with fresh air, and the dress being nearly fire-proof, the diver can enter any place on fire without fear of suffocation. Thus it is a fire-engine and diving apparatus combined. The depth of the diving-helmet breastplate is increased so that it will cover the chest and the region of the lungs, and keep off the pressure in deep water. The submarine lamp will burn eight hours under water, and is supplied with air from the same pump as supplies the diver. The patent is dated 1862, in the name of Mr. C. E. Heinke, and a helmet dress and apparatus made in accordance therewith was placed in Class 10, International Exhibition, 1862, where it claimed considerable attention.

"Many trials of the Messrs. Heinke's apparatus have been made, and with eminent success. The experiments conducted at Portsmouth, in June, 1855, in presence of the admiral superintendent and dockyard officers, gave great satisfaction, the diver remaining half an hour at a time in seven fathoms of water. At Chatham Dockyard, in October, a similar successful trial occurred before distinguished company. It has been tested on the Seine at Paris, under Government command and supervision, and out of five kinds of apparatus was the one selected as the best,—the French exhibitor, M. Ernoux, considering it really perfect! At the Paris Industrial Exhibition it received a first-class medal. We also quote the following from 'The Times':

"August 23, 1860: 'Letters this morning from Point de Galle announce that the whole of the specie of the Malabar—about £280,000—has been recovered. The diving apparatus used was Heinke's patent.'

"September 5, 1860: 'The whole of the diving apparatus in use by the Royal Engineers at Chatham is to be fitted with Mr. Heinke's improved eye-plates.'

"January 24, 1863: 'The whole of the mails and cargo have been removed, by Heinke's diving apparatus, from the wreck of the Colombo. This apparatus, besides its utility in the case of wreck, is in the case of fire even more valuable. Protected by it, persons can advance with perfect safety through the most dense smoke, and obtain an access to the actual source of mischief—an advantage on board ship of incalculable importance.'

"Perhaps few of us consider the many uses to which diving apparatus may be put in the years to come; but it is to firms like the one under consideration that we must look for the initiative. With an eye on the alert for tokens of usefulness in the distant future, the uses of the present will be probably ere long considerably multiplied, rendering easy many now difficult undertakings. All floating structures, those having their foundations beneath the waters, others entirely submerged (be they constructed by man or God, formed of rock or vegetation), may be repaired, blasted, cut away, built, or in any way operated on by the use of diving apparatus. Of what use it may be made in war we know not; but in the interests of peace its conquests may be many and important. From the latter end of the twelfth century to the present, the mind of at least some portion of the engineering world has ever been intent on the discovery of improvements in diving apparatus for the more easy prosecution of submarine labour. The necessities of ocean, but especially her treachery,—the strong waves and contending currents hurrying to destruction on the land, or sinking in the gulfs beneath, the richest argosies of wealth,—have led inventive genius to special effort in this behalf. To Roger Bacon has been attributed the origin of the diving-bell; and from his day the path of improvement can be variously traced. The Emperor Charles V. is reported to have witnessed public trials made with what Schott, in 1564, called 'an aquatic kettle.' In 1588, a sunken vessel—one of the celebrated Spanish Armada—was surveyed by this means; and thenceforward Debrell, Bishop Wilkins, Borelli, Phipps, Triewald, Smeaton, and the Messrs. Braithwaite experimented in this department of useful science, meeting with obstacles and overcoming them; developing for the apparatus fresh means of usefulness, then fitting it to the occasion. By the end of the sixteenth century, improvement had made rapid and decidedly useful and paying progress; for enormous amounts of property had before that time been rescued from sunken vessels, and improvers in diving apparatus had been already honoured by our Government. The time had then to arrive for such thorough operations as to necessitate the diver treading the floor of the sea, to labour there as on land, with thought, energy, and skill, and an amount of accuracy all the more perfect as the submarine work committed to his charge would be more calamitous in its failure than the destruction of any mere land structure. Hitherto the descent had but been into the interior of submerged vessels, to search for treasure, or into caves, no great weight of water having thus to be borne. Triewald (before alluded to) is said to have been the first experimenter in the extended sphere of operations, and to have introduced convex lenses instead of plain glass. Now followed air-condensation, and the necessary apparatus

improved and re-improved; and great engineering works were erected, surveyed, and repaired, so that, in fact, diving operations at once took their stand among the 'necessities.' The noble Plymouth Breakwater had its firm and solid under-water masonry laid, stone after stone, by the aid of the new science. Other great works followed; the ramifications of the new science were extended to less important tasks, and now there are few under-water operations, in ocean, river, or stream—to found, destroy, or prune—that may not be accomplished by the diver, properly equipped. The original outlay or daily maintenance is not so great as to necessarily preclude the use of diving apparatus in small works, where thorough efficiency and economy of time are desired. We hope that the efforts of the Messrs. Heinke in the way of improvement will yet at no distant day render submarine labour but little more difficult, laborious, or expensive than ordinary avocations on land."

The foregoing account is usefully supplemented with the following extracts from the "Reports of the International Jury of the Paris Exhibition of 1855, on C. E. Heinke's Diving Apparatus:"

"CLASS XIII. (MARINE)—*Diving Machines and Apparatus.*—Whilst the loose diving-dress of M. Touboulic may be taken to represent the elements of the art of diving, the different apparatus due to MM. E. Heinke, Siebe, Cabirol, and Ernoux realize, on the contrary, its latest improvements. They are all identical in principle, and consist of a waterproof dress, with a metal collar, on which, by means of screws, is fastened a metal helmet, provided with an air-pipe which receives its supply from a pump placed on the deck when the diving takes place from a vessel, or on the edge of the pit when the operation is to be effected on shore. Covered with this dress, the diver descends to any depth that may be desired. In these apparatus the principal conditions to be considered are—the impermeability of the dress itself, its resistance to the pressure of the water, the continued renewal of fresh air, and the providing the diver with the means of seeing while at work, and of communicating with the surface by a simple and certain system of signals.

"MM. E. Heinke and Siebe have found means of providing, between the dress and the body of the diver, for the introduction and retention of a sufficient quantity of air to insure a proper amount of resistance to the water, and to keep the body in an atmosphere of which the elasticity is always the same. To effect this they inject by the air-hose a greater quantity of air than escapes by the valve in the helmet which gives issue to the foul air and that in excess.

"Indeed, Mr. E. Heinke has made in this respect a remarkably happy improvement by his double-action valve. The outside of the valve is furnished with a slide, which opens or hermetically closes at the will of the diver. When the valve is shut the dress becomes inflated by the excess of air pumped in; the diver is thus rendered lighter than the water, and he consequently rises at once and without trouble to the surface. Should there be any danger at the bottom, or should the signal have failed or have not been promptly attended to, the diver can, by regulating his valve, immediately rise to the surface and give the information himself. This, indeed, lately occurred in the Black Sea, on board the steam corvette the Primauguet, under the command of Captain Reynaud. Mr. Heinke's diver has thus, by regulating the valve, the power of sinking as slowly as he thinks proper, while the other divers, dragged down by the enormous weights placed upon their shoulders to insure their immer-

sion, are compelled to remain at the bottom till drawn up by the cord attached to their sides.

"The apparatus of M. Ernoux is not so complete. The diver who uses this apparatus is not protected, as in that of Mr. E. Heinke, by the introduction of air inside the dress. Instead of escaping by the valve in the helmet, the air is at once forced out (without being able to penetrate the dress) by the holes arranged for that purpose between the metal collar and the top of the dress. The dress is thus continually in immediate contact with the body, for between it and the water which compresses it there is only the thickness of a non-elastic stuff. Without attempting, therefore, to fix the exact limit of depth at which this dress will permit to work, we may nevertheless affirm that Mr. E. Heinke's diver will be able, if necessary, to work with ease at a depth where the diver of M. Ernoux could not remain without danger of suffocation.

"In all the different systems the diver receives the light through lenses of glass or crystal, placed in front of the helmet; but this is so far dangerous that, if the glass happens to break, the water rushes in and suffocates the diver. Mr. E. Heinke is the only one who has obviated the danger arising from this cause. If the glass of his helmet breaks, the diver immediately shuts the escape-valves, and the air rushes out through the broken glass—the only means by which it can escape—and thus prevents the entrance of the water. The diver may even descend with a broken glass, and yet, by the remarkable improvement introduced by Mr. E. Heinke, he may remain submerged without impediment, and continue the operations.

* * * * * * *

"We have only said a few words *en passant* of M. Siebe. His apparatus is the same as that of Mr. E. Heinke, but without the improvements we have pointed out; but the priority in the construction of this class of apparatus—which in itself is a very great merit—seems to belong to him. However this may be, the problem of diving apparatus seems to us to be now practically solved. They will, doubtless, be still further improved; but, such as they are, they are sufficient for the examination of the bottoms of vessels and of screws at sea, and they will be principally employed for these two purposes by the navy, and for all kinds of submarine operations."

An award of a first-class medal was therefore made to Mr. C. E. Heinke, because his diving apparatus was considered the most perfect of the kind which has been produced up to the present time.

"The principal improvement which he has introduced consists in enabling the diver to remain under water when an accident occurs, such as the breaking of a glass, which would otherwise have allowed the water to penetrate into the dress."—Vol. II., p. 41.

Again, it is stated—

"CLASS XIV.—*Constructions Civiles.*—In the apparatus of Mr. E. Heinke the valve is placed on the chest, and the diver can enclose it with his hand at pleasure if any portion of his dress is torn while at work: the current of air then becomes directed towards the opening, and the diver is enabled to ascend without danger."—Vol. II., pp. 197, 198.

Returning to the exhausting air-pump, a number of experiments, illustrating the weight of the atmosphere, may be demonstrated.

EXPERIMENTS WITH THE AIR-PUMP.

Two brass hemispheres, nicely fitting together, with ground edges greased, may be easily separated; but directly they are joined and screwed on the air-pump, which is then set in motion, it will be found that in pumping out the air from the inside a pressure is brought to bear upon the outside; and if, after exhaustion, the brass sphere, usually called "the Magdeburg hemispheres," are unscrewed from the air-pump plate, and handles put on, it will be found that two men, pulling one against another, will rarely separate the hemispheres, which are pressed together with a force of nearly 200 lb., supposing the hemispheres are of a diameter of four inches. When a membrane is stretched over one of the mouths of a cylindrical glass open at each end, and the other is greased and placed on the air-pump plate, the first stroke



FIG. 409.—*The Magdeburg Hemispheres.*

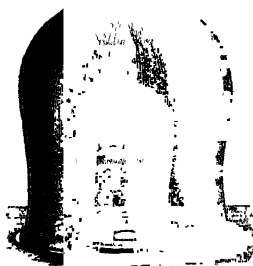


FIG. 410.

of the pump causes the membrane, which should be dry, to take a concave form, and if the air-pump is now rapidly worked, the pressure of the whole outer column of air, of a diameter equal to that of the membrane, is brought to bear upon it, which ultimately breaks in the bladder with a loud noise. As the air exerts a pressure of 15 lb. upon every square inch, the bursting in of the membrane is not very surprising.

To prove that an exhausted receiver is held down by the pressure of the air, take one open at the top, and ground quite flat, as at Fig. 410, and covered with a brass plate, which has a brass rod passing through it, working in a collar of leather, so as to be air-tight. To this rod suspend a small receiver within the larger one, a little way from the bottom. Place the outer receiver on the air-pump, and exhaust it: it will now be fixed fast down; but the small receiver may be pulled up or down with perfect ease, as it is itself exhausted, and all the air which surrounded it removed, consequently it cannot be exposed to any pressure. Let then the small one down upon the plate, but not over the hole by which the air is extracted, and re-admit the air into the

larger receiver, which may then be removed; it will be found that the small one, being itself exhausted, is held down fast by the air which is now admitted round the outside. If the large receiver be again put over it, and exhausted, the small one will be at liberty; and so on, as often as the experiment is repeated.

"This effect," says Imison, who relates the above careful experiment, "cannot be accounted for upon any other principle than the pressure of the air, as the common idea of suction can have nothing to do in the case of the small receiver, which is fixed down merely by letting in the air around it. We ought, therefore, to attribute all those effects which are *vulgarly* ascribed to *suction*, such as the raising of water by pumps, &c., to the *weight* and pressure of the atmosphere."

A column of mercury, 29½ in. high and 1 in. square, weighs, in round numbers, 15 lb.; consequently the air presses with a weight equal to 15 lb. upon every square inch of the surface of the earth.

Galilei Galileo, the immortal mathematician and astronomer, the legitimate offspring of Vincenzio Galilei and Giulia di Corimo Ammanali di Pescia, was the first who discovered the gravitating power and weight of the air; he compared the latter with that of water, and pronounced it to be impossible to raise water higher than 33 ft. by what was then styled *suction*. He proved that suction was the language of a fable, and really meant nothing; and that the rise of water in a pump, expressed in sober, philosophical language, was not "the power of suction," but "*the pressure of the air*."

The pupil of Benedetto Castelli, Evangilista Torricelli, another learned mathematician and philosopher — called, in nearly all the books, *a pupil* of Galileo, although only a resident with the latter a few weeks, as Galileo died three months after Torricelli arrived in his house—this disciple of Galileo, reflecting that mercury was fourteen times heavier than water, considered that a column of quicksilver $\frac{1}{14}$ of the length of 33 ft. of water ought to be an equal balance to the latter; and hence he discovered the true principle upon which the barometer is constructed.

Torricelli filled a glass tube, closed at one end, and about 3 ft. in length, with mercury; then, placing his finger on the open end of the tube filled with mercury, he inverted it in a basin containing the same metal. The mercury he had poured in the tube, measuring 36 in., fell immediately to the height corresponding to the then pressure of the air, say 30 in., and the space above, containing nothing, was called, after Torricelli, the "Torricellian

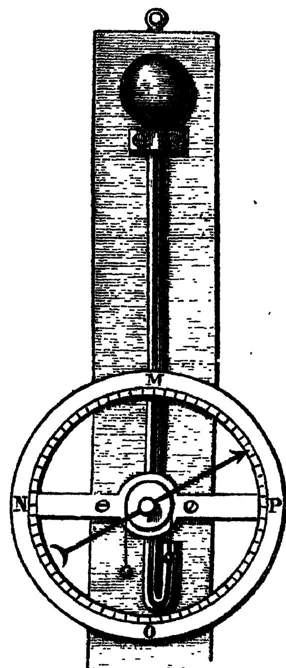


FIG. 411.—*A Weather-glass.*

vacuum." The 30 in. of mercury were sustained by the pressure of the air and it was soon discovered that the fluid metal did not remain stationary; it varied daily, and the variations appeared to precede changes in the weather, and thus gradually it came to be called the weather-glass. (Fig. 411.)

THE BAROMETER.

Two Greek works—βάρος, a weight, and μετρον, a measure—are enlis to give the title to this most valuable instrument, which accurately dem... strates the variability of the pressure of the air. Mercury is about thirteen times heavier than water; consequently a column of mercury 1 in. square and about 30 in. in height will counterbalance a column of water 34 ft. high and 1 in. square at the base, or both will hold in equipoise a column of air of its natural height from the earth, or that aërial mixture which is supposed to be included within a distance of 45 miles of the earth's surface, *i.e.*, starting from the level of the sea.

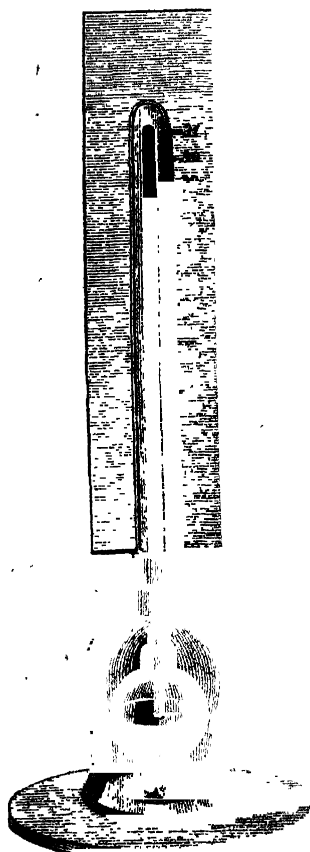


FIG. 412.—*The Barometer in the Vacuum of an Air-Pump.*

The specific gravity of air is taken as unity or one, and it is the standard with which the density of all gaseous bodies is compared. Air at 30 Bar. and 3?° Fahr. is 769·4 lighter than water, and 10,462 times less heavy than mercury.

A barometer, for rough purposes, is soon made. A clean, dry tube of stout glass, called barometer-tube, is hermetically sealed at one end; pure mercury is then poured in until the tube is filled within one inch of the open end; the thumb is now held tightly over the latter, and the air included in the small space already alluded to is slowly passed up and down the tube, in order to collect all the smaller bubbles of air which adhere to the inside of the glass tube. The tube, filled with mercury, is left standing upright, and is gently tapped (say daily for a week), in order to assist the escape of any bubbles of air. It is then inverted in a basin of clean mercury, and, supposing the tube to be 36 in. in length, the mercury may fall to 30 in., and the space between 30 in. and 36 in. is called, as already stated, the Torricellian vacuum.

The barometer thus made, if placed under

the receiver of an air-pump (Fig. 412), indicates, by the falling of the mercury, the amount of vacuum procurable by any pump that the operator may wish to test; and, as before stated, there is always a fractional portion left behind, however excellent the air-pump may be. A pump that will remove 329 volumes out of 330 may be regarded as a very good one.

The more refined instruments required for meteorological purposes are made in the same manner, with the additional precaution of boiling the quicksilver in the tube, so as to get all of the last bubbles of air. It is this which renders them more costly, as many tubes are sometimes broken in the process of boiling. There are many good barometer-makers in London.

Fig. 413 represents a refined instrument, made by Negretti and Zambra, who give the following instructions:

A Standard Barometer, on Fortin's principle, reading from an ivory point in the cistern, to insure a constant level—with mercury boiled in the tube. The barometer-tube, which is $\frac{4}{10}$ of an inch diameter, is enclosed and protected by a tube of brass extending throughout its whole length; the upper portion of the brass tube has two longitudinal openings opposite each other; on one side of the front opening is the barometrical scale of English inches, divided to show, by means of a vernier, $\frac{1}{500}$ of an inch; on the opposite side is sometimes divided a scale of French millimetres, reading also by a vernier to $\frac{1}{10}$ of a millimetre; the reservoir or cistern of the barometer is of glass, closed at bottom by means of a leather bag, acted upon by a thumb-screw passing through the bottom of an arrangement of brass-work, by which it is protected. A delicate thermometer is attached to the brass tube.

Directions for fixing the Barometer.—Having determined upon the position in which to place the instrument, fix the mahogany board as nearly vertical as possible; and ascertain if the barometer is perfect, and free from air, in the following manner:—lower the screw at the bottom of cistern three or four turns, that the mercury in the tube, when held upright, may fall two or three inches from the top; then slightly incline the instrument from the vertical position, and if the mercury in striking the top elicit a sharp tap, the instrument is perfect. If the tap be dull, or not heard at all, there is air above the mercury, and must be driven into the cistern by *inverting the instrument, and gently tapping it with the hand.* Supposing the barometer to be in perfect condition, it is next suspended on the brass bracket, its cistern passing through the ring at bottom of the mahogany board, and allowed to find its vertical position, after which it is firmly clasped by means of the three thumb-screws.



FIG. 413.
A Standard Barometer.

Before making an observation, the mercury in the cistern must be raised or lowered, by means of the thumb-screw, until the ivory point and its reflected image are just in contact; the vernier is then moved by means of the milled

head, until its lower termination just excludes the light from the top of the mercurial column; the reading is then taken by means of the scale on the limb and the vernier.

A very excellent and moderate-priced instrument is that made by Davis and Co., 163 Fenchurch Street. (Fig. 414).

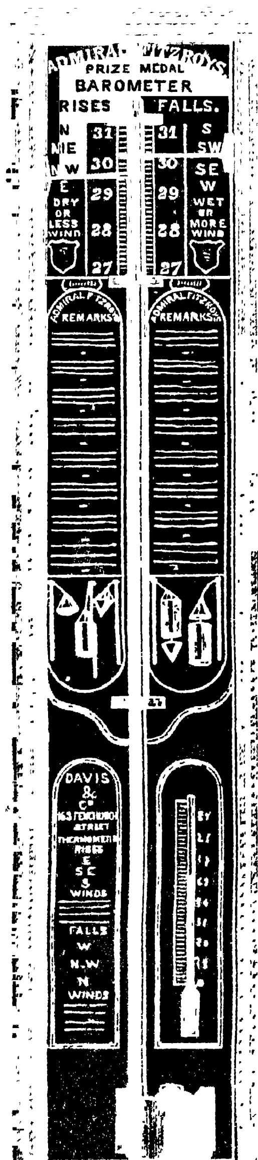


FIG. 414.—*Davis's Prize Medal Barometer and Weather Guide.*

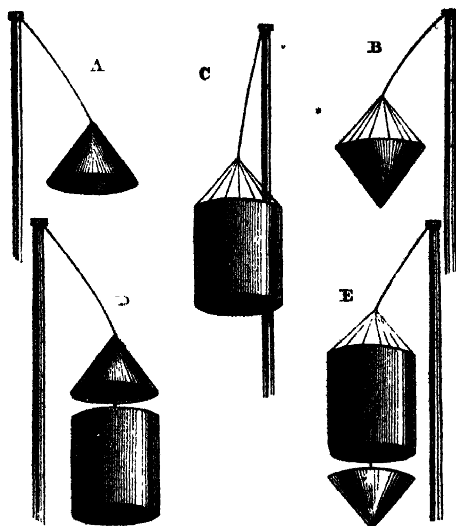


FIG. 415.—*Admiral Fitzroy's Storm-drum.*

A. Gale, probably from north.
B. Gale, probably from south.
C. Expect dangerous winds from opposite quarters successively.
D. Dangerous wind expected from north.
E. Dangerous wind expected from south.

Admiral Fitzroy's name is attached to this instrument, and it consists of the barometer with thermometer, also a table indicating by the rise and fall of the mercury the direction of the approaching winds, with Admiral Fitzroy's special instructions for this instrument. The writer was inclined to suppose, from its low price of fifty shillings, that it could not be very accurate; but, on comparing the instrument for some days with a standard barometer, it was found to be very sensitive, and although not quite agreeing with the standard instrument, was sufficiently near for all ordinary purposes, and, with the

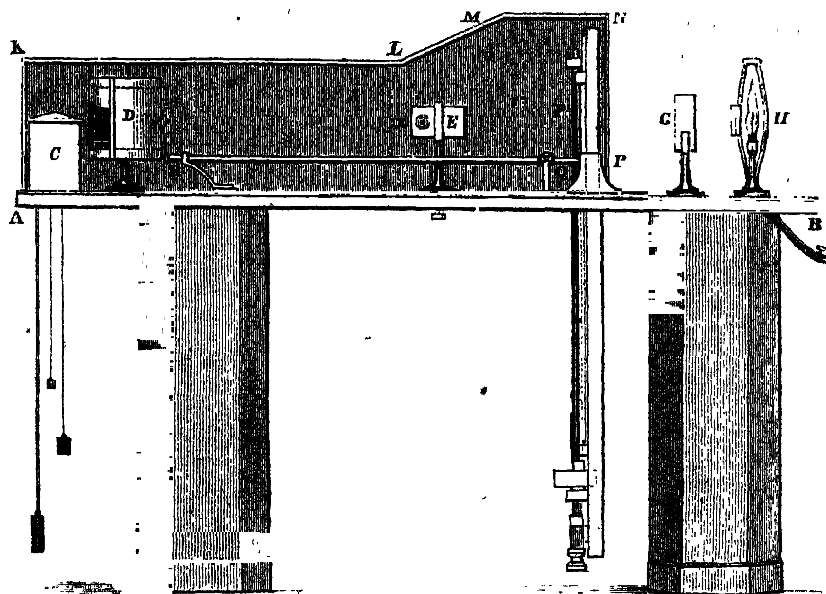


FIG. 416.—*The Self-registering Barometer at Stonyhurst College.*

directions inside the case, renders, as the late Dr. Herapath said, "the indications of Davis's barometer more readily intelligible and trustworthy;" in fact, weather-wisdom has been thus reduced to rules of comparative certainty.

At Stonyhurst College (Fig. 416), also at Kew and other places, there are regular observatories where the rise and fall of the mercury in the barometer is automatically registered night and day.

The thermometer is also registered in a similar manner; likewise the direction and velocity of the wind.

The papers on which the rise and fall of the barometer are registered are called "barograms" (Fig. 417); those of the thermometer are termed "thermograms" (Fig. 419); and the papers that record the direction and force of the winds, "anemograms" (Fig. 420).

By the kindness of the Rev. S. G. Perry, and with the concurrence of the Rev. Father the rector of Stonyhurst, reduced copies of all these are appended, with a drawing and description of the self-registering barometer (Fig. 416).

A B (Fig. 416) is a slate slab supported on two stone piers, similar to those which support the magnetographs. C is the clock which turns the cylinder D, on which the sensitive paper is wrapped. E, a lens for focusing the light which passes over the mercury column at F. G, a lens for condensing the gas-light H. K L M N P is a wooden covering, fitting closely, to keep any scattered light from discolouring the paper on the cylinder. Q R is a level acted upon by the zero-temperature rods, which run parallel to the barometer. *x* is a focusing-screw, which, when once fixed, is never touched,

since any alteration in it would alter the constants of the curves.

In the barogram (Fig. 417), the straight white line enables the observer to see the curve of the upper dark one, showing how the light, which acts upon the paper prepared by a photographic process, has been cut off by the rise of the mercury, or allowed to pass when the latter fell.

Fig. 418 shows how the curve seen at Fig. 417 is reduced to figures; part only of a barogram, X, is shown. This is

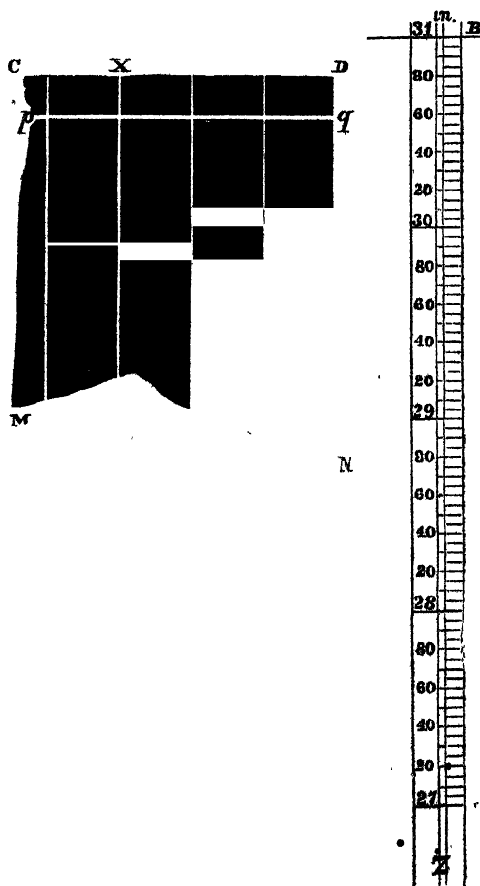


FIG. 417.
Copy of a Barogram from Stonyhurst.

FIG. 418

checked by an ivory scale, Z, by placing A B of the scale Z, on the top line, C D, of the barogram, X; then the reading of the scale at the line M N gives the height of the barometer. The shaded portion of the barogram is the part acted upon by the line of light which passes over the top of the column of mercury. The lens in front of the cylinder inverts the whole. $p\,q$ is for temperature corrections. The graduation of the ivory scale depends, of course, on the constants of the particular instruments used.

A barometrical observation is always corrected for capacity and temperature, capillarity, and for the index error.

The following directions for taking an observation of the barometer are given in "Watt's Dictionary:"

1. Read and correct the attached thermometer, making a correction for index error, if necessary.
2. Adjust the mercury below to exact contact with the fiducial point.
3. Slightly tap the tube near the upper end of the column, and adjust the edge of the vernier to exact tangential contact, the line of vision being horizontal.
4. Record the reading, and work out the correct height as soon as convenient afterwards, as shown in the following example, which comprises all the corrections ever required:

Attached thermometer	58·3° F.
Data. Neutral point	28·861
Capacity	$\frac{1}{33}$
Diameter of tube	·4 in.
Index error to K. O. standard (apart from capillarity) . .	—·014 in.

	Inches.
Barometer reading.	29·964
Correction for capacity	+·033
" " capillarity	+·007
	30·004
" " temperature	—·080
" " index error	—·014
True height of the barometer	29·910

The purchaser of a barometer for scientific purposes should insist on receiving with it an

FIG. 419.—*A Thermogram from Stonyhurst.*

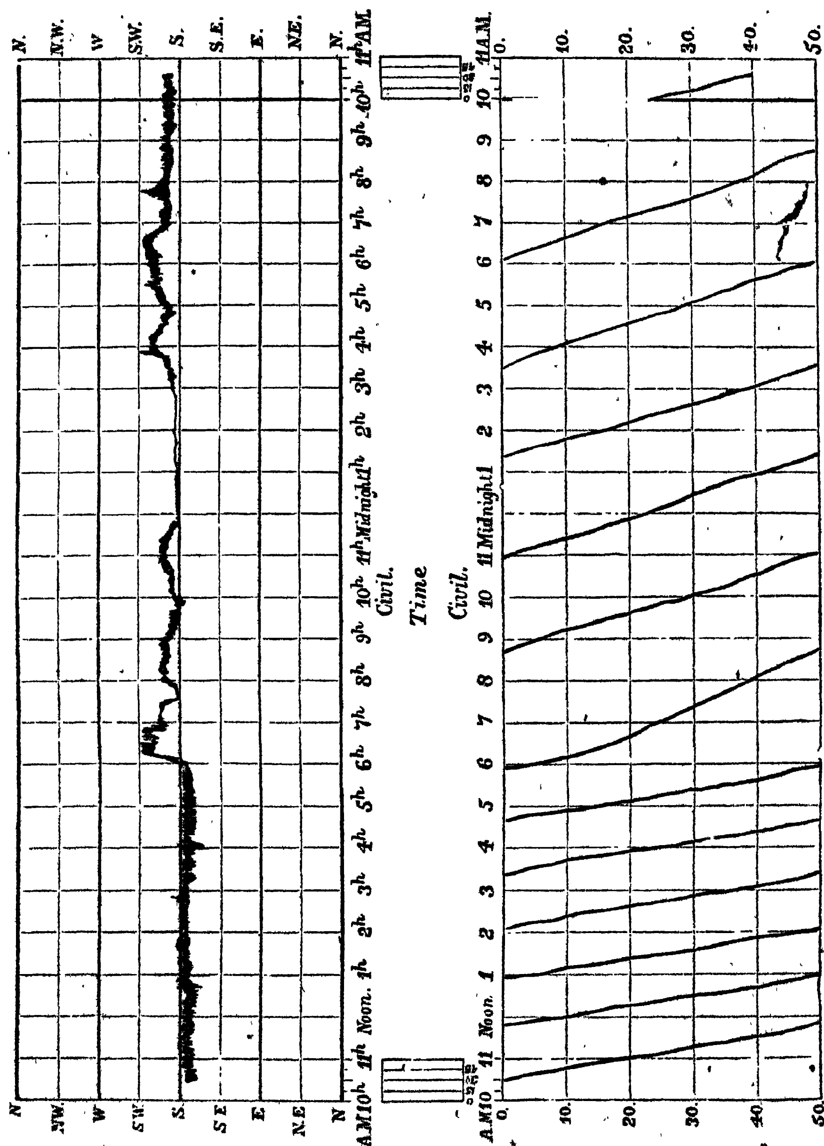


FIG. 420.—*An Anemogram from Stonyhurst.*

authentic certificate of its index error, from comparison with the Greenwich, Kew, or Royal Society's standard barometer.

For meteorological purposes, the observation of the rise and fall of the thermometer taken with that of the barometer is of considerable importance, whilst the record of the anemometer, or wind-gauge, affording anemograms (Fig. 420) such as that of Ostler's self-registering anemometer with the rain-gauge, represent the scientific data that might enable observatories to give notice of approaching storms, especially if the central national observatory receives constant telegrams of the state of the weather from all parts of the world.

More experience derived from carefully conducted observations at a variety of places in England and on the Continent will, no doubt, gradually enable meteorologists to predict with absolute certainty that which Admiral Fitzroy could only do imperfectly by the then obtained data from the various observatories; but what he did is sufficiently encouraging to induce meteorologists all over the world to remember that "unity is strength;" and, by exchanging barograms, thermograms, anemograms, and rain-gauge heights, they can assist each other in forming correct calculations of the general weather to be expected at various seasons and in different parts of the world; they can also give each other warning of the probable approach of any great currents of air or wind, and thus help to prevent the disastrous wrecks which strew the shores of the various countries along which the track of commerce is marked out.

The old-fashioned wheel barometer (Fig. 411, page 441) is still a great favourite, because "those that run may read." Any one can tell the weather, at least theoretically, by looking at its honest old silver face. The wheel barometer means well, but acts somewhat incorrectly, because it works by the rising and falling of an iron counterbalanced weight floating in the mercury; and if this should stick, or the string and counterpoise act indifferently, it is extremely disheartening, after settling a picnic on the authority of the "glass" stating that the weather is not only "set fair," but "very dry," to discover, just as the hampers of provisions are started, and the new bonnets getting into the open carriage, that the weather is insolently defiant, and, not caring a bit about what the wheel barometer says, is just opening a "nice drizzle," sure to improve into a steady "downpour." It is better to get a Davis's two-guinea Fitzroy barometer, and calculate the chances of weather in the regular way, viz., 1st, by what has gone before; 2nd, temperature; 3rd, state of wind; 4th, steadiness or unsteadiness of the barometer.

The Standard Aneroid Barometer is constructed on the same principles as the ordinary aneroid, but with extra care in make and finish to ensure greater freedom of motion, hence more sensibility and accuracy in its readings. The divisions on the dial are very fine, both in quality and space, dividing the reading to a hundredth part of an inch. It has also a scale indicating the pressure of the atmosphere, of the following range—from 1,000 ft. below to 7,000 ft. above the surface of the earth. It is very portable, will act in any position, and is not liable to injury in transit.

Its construction may be thus described:—A nearly flat metal box, exhausted of air, the upper surface or lid of which is firmly held by a powerful spring, connected with the hands by means of a lever and chain, thus, as it were, multiplying the small motion of the pressure of the air by giving an extended reading on the margin of the dial. At the back of the instrument, a screw-head is visible, which, if slowly and carefully turned, will enable the aneroid to be adjusted to a mercurial standard barometer.

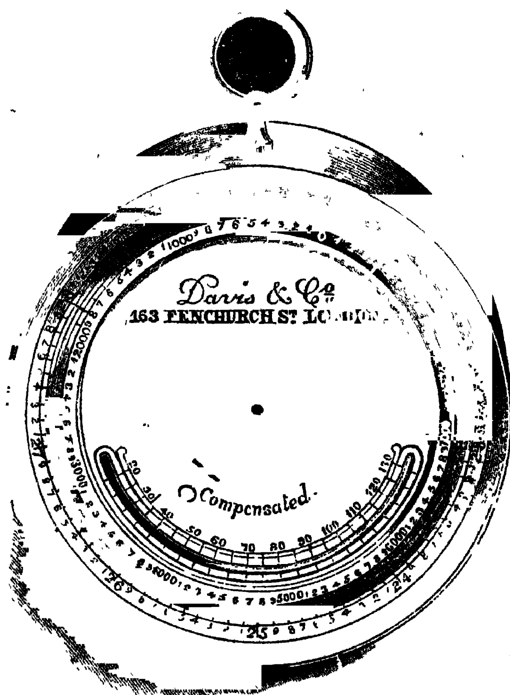


FIG. 421.—*Davis's Standard Aneroid Barometer.*

The air being proved to be material, like water, it was not long before the genius of man said he ought to be able to swim in air as well as in water, or, in plainer terms, to fly.

Dædalus essayed the task, and having been successful in the construction of a *wooden cow* for Pasiphæ (query, was this the original old friend of the modern milkman, the cow with the iron tail—the pump?), and having shut up the dreadful monster, the Minotaur (most likely a hippopotamus), in a labyrinth at Cnossus, for this stroke of benevolence he was imprisoned by Minos, but his old friend the milkwoman (at least, Pasiphæ) released him; but the artful Minos had seized all the ships on the coast of Crete, whereupon Dædalus procured *wings* for himself and son, and fastened them on with *wax*. Strange to say, the classical authorities relate that they *flew safely* over the Ægean, alighting in Italy. This "ower-true tale" has brought unhappiness to the bosoms of many clever mechanicians, who, trying to imitate Dædalus, have only met with the derision of their fellow-men and pecuniary loss to themselves.

The idea which the inventor, St. Martins, endeavoured to realize is that of a self-supporting kite, the string, the restraining power, being represented by the two screws. The inventor maintains that his flying machine, being once

fairly launched, the force of the wind would be resolved by the screws, as by the string of the kite, into two powers, one of which, overcoming the force of gravitation, would keep it stationary in mid-air.

This might, by the barest possibility, be achieved, but only with screws so large and so heavy, and requiring such powerful and weighty machinery, that the whole would virtually gravitate to mother earth, and decline to fly a single inch from the ground. The flying machines hitherto suggested are purely visionary; not one will take itself up, or maintain itself in the air like a bird. The models and drawings of these suggestions are undoubtedly pretty, and that is all that can be said about them: the veritable flying machine is yet to come.



FIG. 422.—*One of the Flying Machines (so called) exhibited by the Aeronautical Society at the Crystal Palace, Sydenham.*

Having connected Galileo's name with the philosophy of the sucking-pump, we may now describe this and other most important forms of pumps, which have been found so useful for various purposes.

The pump was first invented by Ctesibius, a mathematician of Alexandria, 120 years before the Christian era. When Galileo defined the principle upon which the common pump acts, the machine was soon improved. There are three kinds, viz., the sucking-pump, the forcing-pump, and lifting-pump. (See Fig. 423.)

The construction of pumps is usually explained by glass models in which the action of the pistons and valves may be seen.* In order to understand the construction and operation of the common pump, let the model D C B L (1, Fig. 423) be placed upright in the vessel of water K K, the water being deep enough to rise at least as high as L. The valve *a* in the movable bucket G, and the valve *b* in the fixed box H (which box fills the bore of the pipe or

* "Rees's Cyclopædia."

barrel at H), will each lie close by its own weight upon the hole in the bucket and box until the engine begins to work. The valves are made of brass, and covered underneath with leather, for closing the holes more exactly; and the bucket G is raised and depressed alternately by the handle E and rod D *d*, the bucket being supposed at B before the working begins. Take hold of the handle E, and thereby draw up the bucket from B to C, which will make room for the air in the pump all the way below the bucket to dilate itself, by which its spring is weakened, and then its force is not equivalent to the weight or pressure of the outward air upon the water in the vessel K; and therefore at the first stroke the outward air will press up the water through the notched foot A into the lower pipe about as far as *e*; this will condense the rarefied air in the pipe between *e* and C to the same state it was in before; and then, as its spring within the pipe is equal to the force or pressure of the outward air, the water will rise no higher by the first stroke; and the valve *b*, which was raised a little by the dilatation of the air in the pipe, will fall and stop the hole in the box H, and the surface of the water will stand at *e*; then depress the piston from C to B, and as the air in the part B cannot get back through the valve *b*, it will, as the bucket descends, raise the valve *a*, and so make its way through the upper part of the barrel *d* into the open air. But, upon raising the bucket G a second time, the air between it and the water in the lower pipe at *e* will be again left at liberty to fill a larger space; and so, its spring being again weakened, the pressure of the outward air on the water in the vessel K will force more water up into the lower pipe from *e* to *f*; and when the bucket is at its greatest height C, the lower valve *b* will fall and stop the hole in the box H as before. At the next stroke of the bucket or piston the water will rise through the box H towards B, and then the valve *b*, which was raised by it, will fall when the bucket G is at its greatest height. Upon depressing the bucket again, the water cannot be pushed back through the valve *b*, which keeps close upon the hole whilst the piston descends; and upon raising the piston again the outward pressure of the air will force the water up through H, when it will raise the valve and follow the bucket to C. Upon the next depression of the bucket G, it will go down into the water in the barrel B, and as the water cannot now be driven through the now closed valve *b*, it will raise the valve *a* as the bucket descends, and will be lifted up by the bucket when it is next raised; and now, the whole space below the bucket being filled, the water above it cannot sink when it is next depressed, but upon its depression the valve *a* will rise to let the bucket go down, and when it is quite down the valve will fall by its own weight and stop the hole in the bucket. When the bucket is next raised, all the water above it will be lifted up, and begin to run off by the pipe F; and thus, by raising and depressing the bucket alternately, there is still more water raised by it, which, getting above the pipe F into the wide top I, will supply the pipe and make it run with a continued stream. So at every time the bucket is raised the valve *b* rises and the valve *a* falls, and at every time the bucket is depressed the valve *b* falls and *a* rises. As it is the pressure of the air which causes the water to rise and pull the piston G as it is drawn up, and since a column of water 32 ft. high is of equal weight with as thick a column of the atmosphere from the earth to the top of the air, therefore the perpendicular height of the piston from the surface of the water in the well must always be less than 32 ft., otherwise the water will never get above the bucket; but when the height is less the pressure of the atmosphere will be greater than the weight of the water in the pump, and will therefore raise it

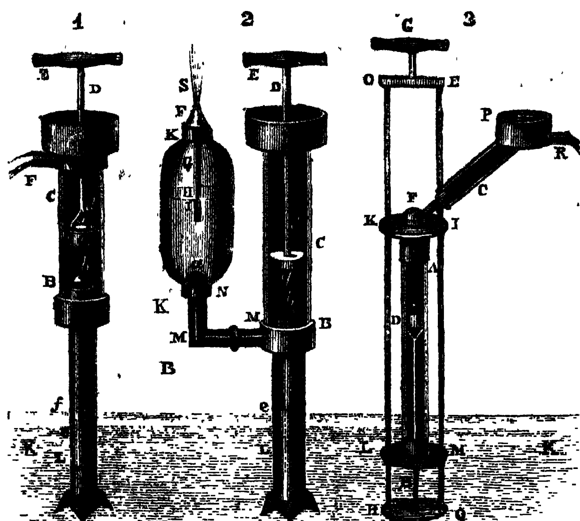


FIG. 423.—*Various forms of Water-Pumps.*

above the bucket; and when the water has once got above the bucket it may be lifted by it to any height, if the rod D be made long enough, and a sufficient degree of strength be employed to raise it with the weight of the water above the bucket without even lengthening the stroke. The force required to work a pump will be as the height to which the water is raised and as the square of the diameter of the pump-bore in that part where the piston works; so that if two pumps be of equal height, and one of them be twice as wide in the bore as the other, the wider one will raise four times as much water as the narrower, and will therefore require four times as much strength to work it.

The FORCING-PUMP raises water through the box H (2, Fig. 423), not in the same manner as the sucking-pump does when the plunger or piston *g* is lifted up by the rod D *d*; but this plunger has no hole through it to let the water in the barrel C, when it is depressed to B, and the valve *b* (which rose by the ascent of the water through the box H when the plunger *g* was drawn up) falls down and stops the hole in H the moment at which the plunger is raised to its greatest height—therefore, as the water between the plunger *g* and box H can neither get through the plunger upon its descent nor back again into the lower part of the pump L *e*, but there being a free passage by the cavity around H into the pipe M M, which opens into the air-vessel K K at P, the water is forced through the pipe M M by the descent of the plunger, and driven into the air-vessel; and in running through the pipe at P, it opens the valve *a*, which shuts the moment the plunger begins to be raised, because the action of the water against the under-side of the valve ceases. The water, being thus forced into the air-vessel K K by repeated strokes of the plunger, gets above the lower end of the pipe G H I, and then begins to condense the air in the vessel K K; for as the pipe G H is fixed air-tight into the vessel below F, and the air has

no way to get out of the vessel but through the mouth of the pipe at I, and cannot get out when the mouth I is covered with water, and is more and more condensed as the water rises upon the pipe: the air then begins to act forcibly by its spring against the surface of the water at H, and this action drives the water up through the pipe I H G F, from whence it spouts in a jet S to a great height, and is supplied by alternately raising and depressing the plunger *g*, which constantly forces the water that it raises through the valve H, along the pipe M M, into the air-vessel K K. The higher the surface of the water is raised in the air-vessel, the less space the air will be condensed into, and therefore the force of its spring will be so much the stronger upon the water, and will drive it with greater force through the pipe at F; and as the spring of the air continues whilst the plunger *g* is rising, the stream or jet S will be uniform as long as the action of the plunger continues; and when the valve *b* opens to let the water follow the plunger upwards, the valve *a* shuts to hinder the water which is forced into the air-vessel from running back by the pipe M M into the barrel of the pump.

The LIFTING-PUMP differs from the sucking-pump only in the disposition of its valves and the form of its piston-frame. This kind of pump is shown at 3, Fig. 423. A is a barrel fixed in a frame, I K L M, which is immovable, with its lower part communicating with the water. G E Q H O is a frame with two strong iron rods movable through holes in the upper and lower parts of the pump I K and L M. In the bottom of this frame Q H is fixed an inverted piston B D, with its bucket and valve upon the top at D. Upon the top of the barrel is fitted F R, either fixed to the barrel or movable by a ball and socket, but in either case water and air-tight. In this part at C is fixed a valve opening upwards. It is evident that, when the piston-frame is thrust down into the water, the piston D descends, and the water below will rush up through the valve D and get above the piston, and that when the frame is lifted up the piston will force the water through the valve C into the cistern P, there to run off by the spout.

The PLUNGER FORCE-PUMP, used so extensively for draining mines, is a most important part of the expensive machinery required in Cornwall and other parts of the world where minerals are dug from great depths.

This pump is wholly unaffected by the pressure of the air, and is worked by the force of the steam engine which is expended in lifting the pump-rods and solid plunger. The latter fits the barrel of the cylinder of the pump, and slides through a collar of leather, so that it works air-tight, like the piston of a hydraulic press.

As the plunger rises, a valve opens inwards and admits the water; the next movement causes the plunger and pump-rods to descend, and these represent a great weight and mechanical power, which, shutting the lower valve, force the water upwards through another valve, and by this great pressure the water is pumped to a considerable height.

To prevent excessive pressure upon the parts of a single pump, it is usual, where the depth of the mine is considerable, to have a series of plunging force-pumps called "lifts," and by passing the water from one cistern to another it is gradually raised to the top of the mine-shaft.

The records of the pumping work done by the famous Cornish engines are very remarkable, and have already been spoken of in the article on the Steam Engine, page 191.

A beautiful illustration of the pressure of the air is shown in the simple con-

trivance called the Syphon. This consists of a bent pipe, whose "legs," as the two portions are called, may be of equal or unequal lengths. If the former, the syphon, when filled with water and placed in a vessel containing the same, must be tilted in order to get a difference in the length of the column of water;

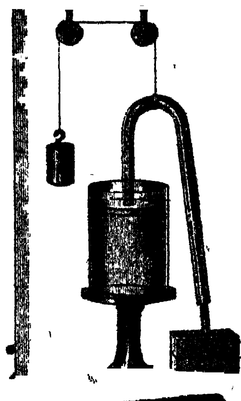


FIG. 424.—*The Syphon.*

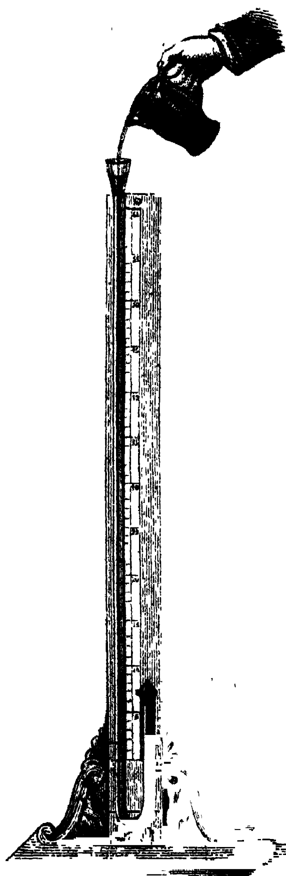


FIG. 425.—*The Law of Marriotte.*

and if this be not done, the syphon whose legs are equal in length will not act. Hence it is usual to have one leg longer than the other; and by attaching a cord and counterweight the syphon may be gradually lowered into the vessel as the fluid is removed.

In order to make a syphon act, it is necessary first to fill both legs quite full of the liquid, and then the shorter leg must be put into the vessel to be emptied. Immediately upon withdrawing the finger from the longer leg, the liquid will flow.

If the short end of the syphon be passed through a cork, fitting air-tight into a bottle quite full of water, the syphon will not act, although the greatest force, with the mouth or other means, may be employed to suck the water into the syphon. This experiment shows that the term "suction" means nothing, and that the syphon will only act when the pressure of the air is admitted to the inside of the bottle by removing the cork. In this experiment the bottle must be quite full of water: if any air is left under the cork, it will expand when the exhauster is applied, and drive the water into the syphon-tube.

A syphon higher than 33 ft. would not act, because the pressure of the air is balanced by the height of the column of water; so also with mercury, the latter will flow through a syphon, provided the utmost height does not exceed that of the barometer at the time it is being used.

The intermitting or reciprocating springs are good examples of natural syphons which only flow when there is sufficient water to fill the longer channel, vein, or leg, that passes from the cavity in the earth or rock in which the water collects.

Air, in common with many other gases, is one of the most elastic bodies in nature. Dr. Miller says it may be stated, without sensible error, that, within the limits of ordinary experiment, the volume of an aëriform body is inversely as the pressure to which it is exposed; consequently, by doubling the pressure we halve the volume, by trebling it we reduce it to one-third; but the elasticity is increased directly as the pressure: by doubling the pressure we double the elasticity. These facts are strikingly illustrated in the following experiment, devised by Boyle, and more accurately performed by Marriotte. (Fig. 425.)

Take a bent tube of thick glass (that called barometer-tube is the best) of uniform bore, one limb or leg of which is about 12 in. long, and furnished with a stop-cock, the other limb being 6 ft. in length, and open at the top. Pour a little mercury into the bend of the tube, and close the stop-cock.

The air in the short leg is now of the same elasticity as that of the atmosphere at the spot; and the air at the surface of the earth is under the pressure due to the weight of its own superincumbent mass. The amount of this pressure is ascertained by observing the height of the mercurial column in the barometer at the time. Next, pour mercury into the open and longer limb of the bent tube; the air in the shorter limb will slowly diminish in bulk. When the mercury in the longer limb stands above the level of that in the shorter one, at a height exactly equal to the height of the barometer at the time, say 29·92 in., the compressed air will occupy a length of the shorter tube exactly equal to one-half of that which it did at the beginning of the experiment; the air is subject to a pressure exactly double.

On adding more mercury, till the length of the column in the long tube above the level of that in the shorter is equal to twice the height of the barometric column, the pressure will be increased threefold; and the air will now occupy only one-third of its original bulk.

It is difficult to find a law without an exception; and the researches of Despretz, followed by the more elaborate experiments of Regnault, show that the law called Marriotte's is a limited law, and does not apply in all cases.

For the permanent gases, oxygen, hydrogen, and nitrogen, and also for gases which are only liquefied by enormous pressure, the law is maintained for many atmospheres; but, with gases easily liquefied, they are found to

take a smaller bulk than the calculated volume when they approach the point of liquefaction. The following are some of Regnault's results, and they show considerable deviations from Marriotte's law in four important gases under great pressures:

Pressure in Atmospheres.	Air.	Nitrogen.	Carbonic Anhydride.	Hydrogen.
1	1·000000	1·000000	1·000000	1·000000
10	9·916220	9·943590	9·226200	10·056070
20	19·719880	19·788580	16·705400	20·268270

The elasticity of hydrogen, therefore, increases even *more rapidly* than the pressure: with the other gases the elasticity does not quite keep pace with it. It would seem, from these experiments, as if there were more probability of liquefying oxygen than nitrogen, and both these than hydrogen.

The elasticity of air is easily demonstrated by placing a closed flaccid bladder under the receiver of an air-pump: when the air is removed the bladder swells up, and will burst if too much air has been left in it. On readmitting the air, the bladder sinks again to its former bulk.

An empty flask, inverted in a glass containing some coloured water, and placed, like the bladder, under a receiver, which is gradually exhausted, shows the expansion of the air. Directly the pressure is taken off, bubbles escape in large quantities from the mouth of the flask; and if the pumping be continued until no more escapes through the water from the flask, it is almost instantly filled with the coloured water when the air is permitted to rush into the receiver that encloses it.

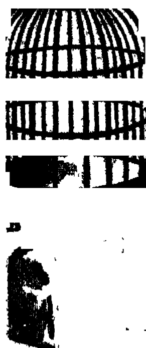


FIG. 426.
A, Wire Cage; and B, Bottle.



FIG. 427.—*Square Bottle burst by the Elasticity of the Air.*

It is in this way a bottle may be burst or the cork violently driven out when placed under similar circumstances.

The bottle is usually made very thin and square; it has a cap cemented upon it, with a bit of oiled silk, which acts as a valve, and opens outwards.

When the bottle with its wire cage is placed under a proper receiver, and a vacuum produced, the air by its elasticity escapes from the interior, because the oiled silk valve opens outwards; on permitting the air to flow into the receiver the valve closes, and as the pressure is now 15 lb. on every square inch, the bottle is usually crushed with the superincumbent pressure.

Or the experiment may be reversed, by making the valve open inside the bottle; then, on pumping out the air from the receiver which encases it, the elasticity of the air in the bottle is checked by the valve shutting; and when a sufficient vacuum has been obtained, the thin square bottle bursts.

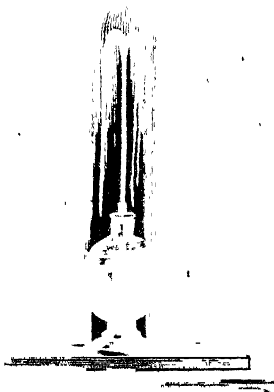


FIG. 428.—*Miniature Fountain—Water forced out by the Elasticity of the Air.*

When a long receiver is placed over a glass bottle containing water, and closed with a tight-fitting cork, or, better still, a brass cap, through which a tube passes, a miniature fountain is obtained when the elasticity of the air becomes sufficiently great to drive out the water from the bottle through the jet.

The Piezometer, as made by Mr. Ladd, is a most useful and safe apparatus for showing the condensation of certain gases which are easily liquefied. (Fig. 429.)

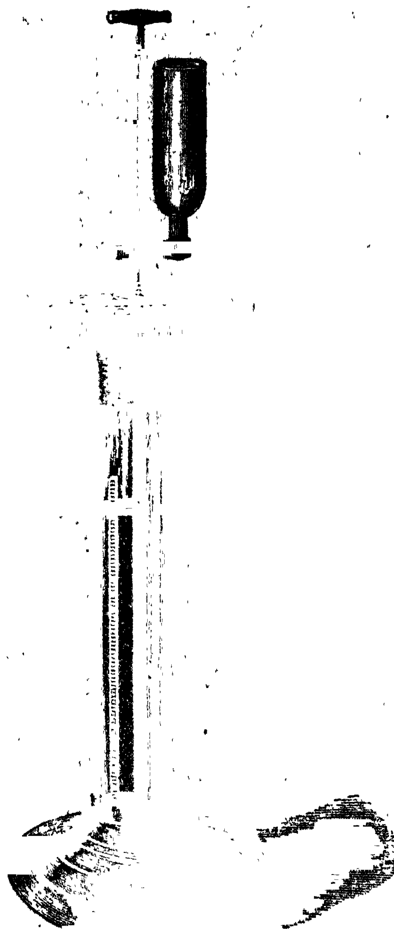
A very stout vessel encloses a tube containing the gas to be liquefied, which is further surrounded by water; and by a clever arrangement of bends in the tube, it is cut off from contact with the water by mercury, provided, of course, the gas does not act upon it. The strong glass vessel is provided with a very stout cap, which is securely fixed and cemented to the top, and this carries the vessel containing water, which is gradually pumped into the vessel; in this way the pressure is so equally applied, that the tube enclosing the gas is not subjected to any unequal force, and by conducting the experiment steadily there is no fear of breaking the outer vessel, in which, of course, a proper pressure-gauge is inserted.

The resistance of the air and its materiality are well shown whenever we try to run with an extended umbrella in our hands; but even this simple truth is nicely illustrated by a miniature double windmill, which is placed under a receiver provided with a rod passing through a collar of leather to which a hook is attached. (Fig. 430.)

The sliding hook enables the operator to set the fans in motion first in air, when the fans with the flat sides exposed to the air come to rest before the fans which cut the air edgeways like a knife.

On pumping out the air from the receiver and again setting the fans in motion, they come to rest at the same time, because there is no longer any resistance to their motion, which is produced by one spring, and, being equal, gases whoth come to rest together.

for many ainea and feather glass is another example of the same kind.



Some feathers and gold pieces are placed on a drop which is fixed air-tight with grease on the top of a very long cylindrical glass placed upon the air-pump plate. It is usual to have three drops. The first time, when the receiver is full of air, the gold piece reaches the air-pump plate first, and is followed by the feather, because the air resists its downward tendency, and the weight or gravitating force of the feather is so slight and spread over so large a surface. When the air is all pumped out and a second drop allowed to fall, the gold and feather fall together, and even the skilled and experienced umpire of a horse-race would be unable to detect any difference in the time of their fall through the large jar and their arrival simultaneously on the plate of the pump. The third drop would of course corroborate the second, as it sometimes happens that the rapid fall of the gold and feather acts as a surprise, and the result is not properly observed the first time.



FIG. 429.—*The Piezometer made by Mr. Ladd.*

FIG. 430. *The Mill with two Fans.*

The application by Mr. Barker, of Paris, of the pneumatic lever to the organ has wondrously reduced the labour of playing the instrument and effected quite a revolution in the touch, and the organ can now be played upon almost with the same facility as the piano.

"It has also been mentioned* that the compressed air in the wind-chest

* "The Organ." By E. J. Hopkin.

became a second source of resistance to the touch of the performer: this latter fact is discernible even in small organs of which the sound-boards are palleted in the ordinary way, by striking a chord in the bass part of the manual first, without the bellows being blown; then with the wind in, when the additional resistance which the organ-wind causes will be at once perceived. In large organs which have pallets of increased size throughout the sound-board, with two pallets in the bass, the amount of spring and wind-resistance is of course much increased, particularly where there are octave and double couplers causing six or seven pallets to operate in one key. But in instruments of the first magnitude, containing as they now do some stops on a heavy pressure of wind, the resistance becomes too great for even the most muscular finger to control without much fatigue. In such cases, it being beyond the power of the several devices to remove the disagreeable stiffness from the touch—or perhaps none of them may be adopted—some contrivance is required that shall bodily overpower the resistance. The pneumatic lever performs this necessary duty most efficiently, and in doing this converts the organist's antagonist into his assistant.

"The first idea of a pneumatic lever originated with Mr. Booth, organ-builder, of Wakefield; but his appliance, made in 1823, was not intended for key movements. The merit of discovering the pneumatic lever as a means for lightening the touch of large instruments is claimed by and rests between Mr. David Hamilton, of Edinburgh, and Mr. Barker, late of Bath, but now a resident of Paris. Mr. Hamilton added a movement of the kind to the organ of St. John's Episcopal Church in that city in 1835. At what earlier period he had completed his model is not stated; but in 1839 a paper was read at the meeting of the British Association at Birmingham explanatory of a pneumatic lever which he then exhibited.

"Mr. Barker's first attempts were made with a cylinder and piston, which were afterwards abandoned in favour of small bellows. In the first instance he endeavoured to introduce his apparatus into England about 1832; experience, however, in large organs was then wanting in this country, and his endeavours were unsuccessful. He therefore went to France, where the subject was better known, and the value of the new principle was appreciated. It was introduced in the great organ of St. Denis (1841), and has since been applied to a number of large instruments in the principal churches of France, as, for instance, the Madeleine and St. Vincent de Paul, &c.

"The pneumatic lever, as made by different organ-builders, varies slightly in detail, but the following is the principle in all:

"The upper member of the lever is formed very like a small concussion-valve. (See A, Fig. 431.) The former shows the lever closed, the other open. Beneath the lever are two little chambers, *c c* and *d d*, between which passes a third, *e e e*; below, again, is a kind of back-fall, *o o*, which controls two circular pallets, *b b*, in such a manner that when one is open the other is closed. Lastly, to the rising end of the lever a small lug is attached, which draws up a tracker that sets the several key movements in motion. Upon pressing down a key on any of the manuals, the movement draws down the near end of the back-fall *o o*, causing the far end to rise, which motion places the circular pallets *b b* in the position shown in the figure. Some of the wind from the chamber *c c* now passes downwards through the uncovered pallet-hole, traverses the passage *e e e*, raising and filling the pneumatic lever, *a*, which draws up the tracker, communicating the impulse to all the sound-board

pallets that may be attached to the controlling key; the circular pallet in the second chamber, *d d*, at the same time closes, and prevents any escape of wind. When the finger is withdrawn from the key, the position of the back-fall, and consequently of the circular pallets, is reversed, as shown in the figure. The supply of air from the wind-chamber is now cut off by the descent of the pallet; at the same time the second pallet in the chamber *d d* is raised, allowing the wind to descend through the pallet-hole, and to escape through the opening *z* into the atmosphere. The contents of the lever being thus exhausted, it returns to its state of rest, as shown at B, Fig. 431, the rapidity of the change being accelerated by a spring.

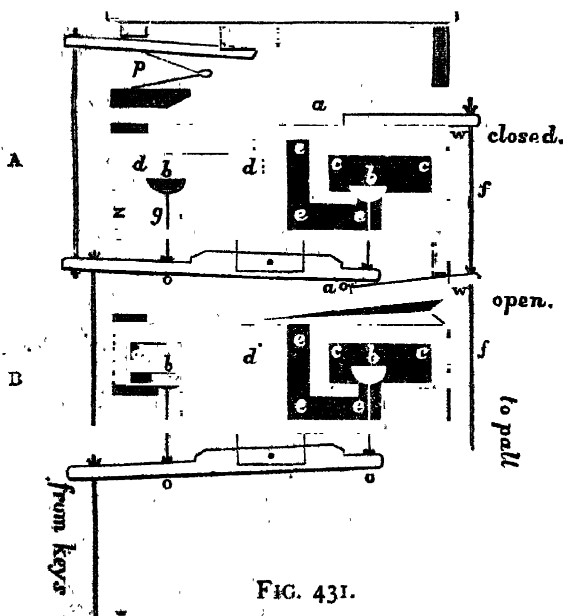


Fig. 431.

"In consequence of the width of the pneumatic lever—about 3 in. only—every fifth lever is placed in the same row; hence the pneumatic action always appears in five rows, as shown in the general section. The pneumatic action which effects such remarkable results as those already detailed is not entirely unattended with disadvantage: in many of the specimens made by the best builders, English and Continental, the working of the levers is as audible as the motion of the old rattling key movements of old organs. This arises partly from the nature of the action itself, which to be effectual must also be very energetic. Nevertheless, the defect alluded to will, no doubt, be speedily ameliorated, if not entirely removed, under the exercise of the ingenuity possessed by so many English builders."

Nearly all the experiments which have been explained serve to prove the mechanical power of the atmosphere; and the question how it could be converted into a motive power available for the conveniences of society has been

a problem of great interest to engineers. Even two centuries ago the notion was entertained of producing motion economically, for the purpose of transit, by means of the pressure of the atmosphere. The original thought may at least be traced back with certainty to the celebrated Dr. Papin; in succession long afterwards came Lewis, Vallance, Medhurst, and Pinkus, whose speculations excited in their day some attention. Towards the close of the last century Murdoch was devoting his attention to this subject. The means of propulsion he proposed to employ was watery vapour working an air-pump; his plan, however, consisted simply of an exhausted tube, through which might be propelled a hollow sphere containing letters and packages. In the year 1810 a proposal was made by Medhurst, the Danish engineer, to put letters and goods in a canal, 6 ft. high and 5 ft. wide, and containing a road of stone and iron, and project them by means of atmospheric rarefaction and condensation. In 1824 an Englishman—Mr. Vallance—made a similar suggestion. His daring plan was to connect Brighton and London by means of an enormous tube, through which, by pumping out the air, carriages were to be propelled with the velocity of a cannon-ball. 'Another proposal was made by Medhurst: he speedily devised means of propelling his carriage in the open air, and of making a communication between the interior of his propulsion-tube and the outside, preserving it at the same time air-tight. The opening was to be closed by a hydraulic apparatus called a water-valve.

Beautiful as Medhurst's scheme was in theory, it was at that time impracticable, and his experiments were unsuccessful: the water-valve refused to exclude the air from the tube. In this state was the contrivance when taken up by Mr. Pinkus, who suggested the rope-valve, which likewise failed to keep the tube air-tight, and was in turn abandoned.

Another inventor came forward in the person of Murdoch's pupil in the Soho factory—Samuel Clegg. The valve invented by him, in conjunction with Mr. Jacob Samuda, of the Southwark Ironworks, gave the final touch to Medhurst's proposal, and led to the construction of the Kingston and Dalkey, the Croydon, and several other atmospheric lines. These lines at last yielded to the locomotive, and ceased to exist.

Murdoch and Vallance proposed the use of a pneumatic tube for the transmission of parcels. With them the motive power and parcel-carriage were both to be in a tube. It is the same with regard to the arrangement of the Pneumatic Despatch Tube of the present day. Medhurst and Vallance proposed to use a pump; but the Despatch Company now attain the same object with an artificial blast, or wind produced by means of a revolving fan.

Mr. Latimer Clark used pneumatic tubes for several years as a means of intercommunication between the Electric Telegraph Company's offices at Lothbury and their branch stations at Cornhill, the greatest length of the tube being three-quarters of a mile. Any one wishing to send a message by telegraph—say to Edinburgh from Cornhill—the message is written down on a piece of paper, rolled up in a small gutta percha box, and placed in the tube; by the pressure of the atmosphere it is quickly blown through the tube, just like a pea out of a pea-shooter, and falls out of the end of the pipe at Lothbury; the box is opened, and the paper with the message written upon it is handed over to the operator at the telegraph instrument in connection with Edinburgh, and the message is instantly sent.

The Pneumatic Parcel Despatch tube, delineated at the head of this article, p. 433, Fig. 401, is now working most successfully between the arrival platform

of the Euston Square Station and the North-Western District Post Office in Eversholt Street; and it is better, for the sake of simplicity, first to explain the arrangements which are made for the purpose of sending carriages containing letters to and fro.

On entering the building erected for the necessary machinery at Euston Square, the engineer in charge points out the pneumatic tube, which is very much like an elliptical gas-main, 33 in. by 30 in. wide, and laid at an average depth of about 9 ft. below the road.

The pipes are made in 9 ft. lengths, with socket joints filled in with lead to keep them quite air-tight, and on the inside—at the bottom of the tube—are cast-iron rails 2 ft. apart. The car to run on these weighs nearly 8 cwt., and is about 8 ft. long, and runs upon four wheels 20 in. in diameter. We have thus, in a very few words, described almost the plant and rolling stock of a Pneumatic Despatch Railway. The car, when placed in the tube on the rails, is blown from end to end, backwards and forwards, as may be required. As we have already seen, air has weight, and this brings it under the influence of the laws of centrifugal force, which give it a tendency to fly off with more or less pressure, according to the velocity with which it is whirled round from a centre. It is this well-known law which is taken advantage of in working the pneumatic tube. At the side of the tube in the small building at Euston Station is a hollow iron wheel working in an air-tight box. This wheel is 21 ft. in diameter, with a thickness of about 2 ft. at the nave or centre—a thickness which gradually diminishes towards its outer circumference, so as to give it the same cubical contents at the rim as at the middle. This wheel is connected with a steam-engine of about 17-horse power, which turns it at a velocity of from seventy to ninety miles an hour, when the air which is drawn in through the centre is thrown off from its periphery with a force which gives a pressure of from 5 to 7 oz. on the square inch,—very nearly the pressure of a hurricane, and all of which, by opening a valve at the end of the tube, is driven through it with almost irresistible velocity. The cars when on the rails inside the tube almost fill it, and expose a surface of nearly 5 ft. square to the blast. They are driven along at the rate of nearly thirty miles an hour.

The whole apparatus is of the most simple, cheap, and effective character, and reflects great credit upon its engineer, Mr. Rammel, for the ease and certainty with which the air from the wheel sends one or more carriages, heavily laden, from one end to the other. For demonstration at the Polytechnic, a little model of wood was constructed about 20 ft. long. There were two carriages; the passengers consisted of a party of white mice, and they were blown from one end of the tube to the other by means of the blast of air from a fan-blower which was set in motion.

The company proposed to lay down a line of 48-in. tubes to form pneumatic stations in connection with the Camden Town Station of the London and North-Western Railway—a central site in Holborn—the Smithfield new market; in Gresham Street, in connection with the large carrying firms for goods and parcels; the General Post Office; Covent Garden Market; and the new terminus of the South-Eastern Railway at Charing Cross. It is stated that Messrs. Pickford alone convey 400 tons of parcels a day through London, at a cost of ninepence per ton; whereas the Pneumatic Company could do the same work quicker at a penny a ton a mile, and yet gain largely by the undertaking. Between the Pneumatic Despatch and the Underground Railway, which should amalgamate, the days ought to be fast approaching

when the ponderous goods vans that now fly between station and station shall disappear for ever from the streets of London. If this could be brought about by the Pneumatic Despatch Tube, it would be of great service to the public.

In a brilliant leader of the 9th November, 1865, "The Times" thus speaks of the pneumatic principle, which, unhappily, in these depressed engineering times seems to be in abeyance:

"Every dog has its day, and even the elements have their turns. Earth, air, fire, and water contend which shall render the greatest service to man, and enjoy the foremost place in the continual triumph of nature and art. In the single matter of locomotion, earth first was everything, and man trudged, rode, or drove. Then water had its turn, and man paddled, rowed, sculled, drifted, or, with earth's aid, punted or was pulled. Then air lent a wing, and the sail carried him across gulfs and oceans. Then fire, or rather steam, the child of fire and water, enabled him to beat the winds and currents, first on water, then on land. At this time we can hardly see by what infatuation we land lubbers allowed the stormy ocean to take the lead of *terra firma* in the use of steam for locomotion. We were actually laughing at the prejudices of old skippers when we had not a thought of steaming by land. But now comes a new move, whereof no man can see the end, though it begins timidly and awkwardly. Air is now the performer. It comes upon the scene with much modesty, as if knowing itself to be suspected of wildness, treachery, and caprice. It only asks to operate in strong iron tubes, and tunnels of masonry in the solid ground. Like the ass of Scripture, which is not as our degenerate specimens, it wants the bridle, not the whip. We have only to raise the wind, a process easier in these days than when Lord Bacon put 'impressions of the air and raising of tempests' among the *magnalia naturæ*. The wind once raised, it will go as we direct it, but still a prisoner, and only revolving to and fro in its subterraneous labyrinth. The notion is so simple that when the thing is once done everybody will ask why it was not done before. Boys will break windows, and savages before this have pierced the tough skin, with pea-shooters. Indeed, everybody knows the power of wind under due control. Everybody has seen the 'lorry' with half-a-dozen men or more hurrying on under no other propulsion; and woe to a full-sized railway carriage if it be caught by a too favourable gale. But it is quite plain that the friction of an ordinary carriage on rails cannot be a greater obstacle than the resistance of the water to a laden ship, which nevertheless is soon overcome by even a moderate breeze. So this is nothing more than land sailing, with two simple differences as compared with sea and river sailing. The track and the wind must be fixed and in accord. In fact, the ship must be blown through a tube."

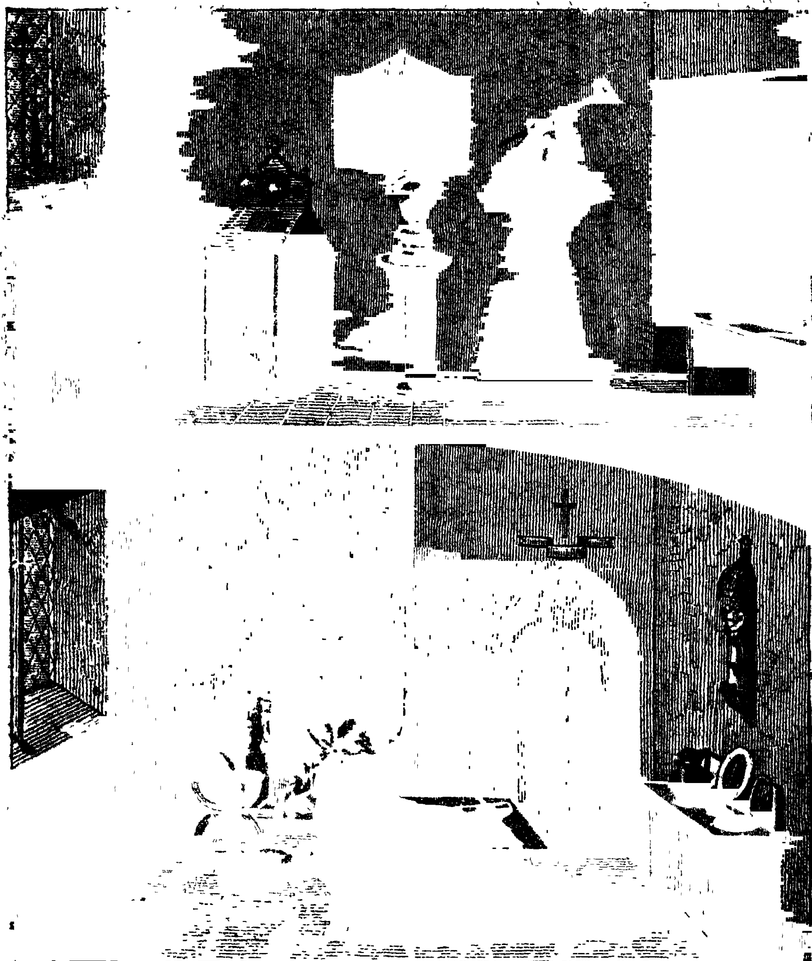


FIG. 432. –*The Talking Head of Albertus Magnus.*

ACOUSTICS.

THE science which treats of the nature and laws of sound has received considerable attention from learned men. 500 B.C., Pythagoras determined that notes of music varied precisely in the ratio of the length of the strings used. Two hundred years after his time, Aristotle wrote upon sound, and affirmed that the number of vibrations performed by strings or by the air in pipes is inversely as their lengths; and that sound is transmitted to the ear by similar vibrations communicated to the atmosphere. Sixteen hundred years after Christ, Galileo rediscovered what had been known to the ancients,

and taught that sound is a vibration of the air, and that musical sounds differ only in the frequency of the vibrations which produce them, whilst a musical string preserves its uniformity of tone by performing its vibrations in equal times.

Passing at once to the beginning of the present century, we find Dr. Thomas Young reviving the undulatory theory of light, and at the same time enriching the science of acoustics with much original matter. The names of Chladni, Savart, Wheatstone, and Tyndall bring us to the present period. Amongst the French philosophers who have laboured industriously in the science of acoustics none are more distinguished than M. Marloye, whose introduction to a catalogue of the principal apparatus for demonstrating the science of acoustics, made by Charles Chevallier, enunciates some very original views, and is therefore translated as follows:

MARLOYE'S INTRODUCTION TO CHEVALLIER'S CATALOGUE.

Fifteen years ago Marloye said, of all the branches of physics, that of acoustics is certainly the least advanced. Perhaps for this reason it now attracts the most attention in Europe, as offering the widest field for investigation. And yet the progress of this science is so slow that each professor of physics might individually imagine he was the only person occupied in its cultivation. Now, if this science advances but little, notwithstanding the unceasing efforts of a great number of talented men, it is evidently because we have arrived at a point at which means of observation are wanting to penetrate further into the secrets of Nature.

Up to the present time, strange to say, we have used our eyes more than our ears in the study of acoustics, and, when we have not been able to employ them, they have been supplied by calculation and by imagination. Thus, thanks to ingenious devices for making the vibratory motions of solid bodies sensible to the eye, we have acquired much information concerning the vibrations of strings, plates, rods, &c.; but what do we know of the vibrations of

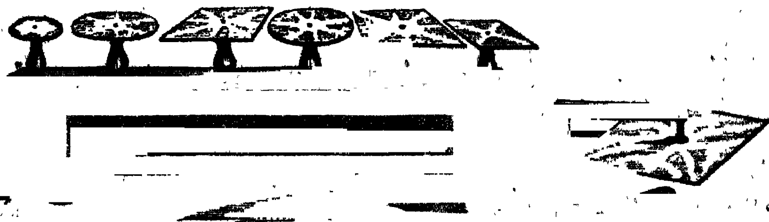


FIG. 433.—*Chladni's Sand Figures.*

liquids and of gases? We are aware of many formulas, based on conjectures more or less probable, but know little or nothing of absolute facts, since we still make researches to ascertain how the air vibrates in the tubes of an organ. The reason is this: the vibrations of liquids and, above all, of gases, having been hitherto inaccessible to the eye, there remained, to follow the thread of so many different motions, no other guide but the ear, which, from not having received an education adapted to this kind of study, has been frequently use-

less under circumstances where its aid was indispensable, and even when it heard all that we desired to ascertain.

It appears, however, that the necessity of an ear instructed for the study of acoustics has been felt at all times; for we still find professors of acoustics more or less musicians, and at the present day, when a person acquainted with general physics wishes to devote himself to the study of this science, he commences by learning music, if he be not already acquainted with it. He certainly ought to know something of music; but it is an error to suppose that one must be, or that it suffices to be, a musician to form an accurate judgment of sounds in general: we may even say that musicians are bad appreciators of sounds not used in music—and they are assuredly the more numerous; sometimes they even judge wrongly of musical notes when the relations of these notes to each other do not approach to musical precision, from a habit they have acquired of not listening to sounds which are grating to the ear.

When a musician hears sounds, what strikes him is the notes they represent, and their exact mutual relation, not so much from their musical interval as from their relation of note to note, and what he listens to is their tone and intensity; from whence it results that, the moment the sounds he hears no longer produce on him the impression of notes, he hears only noise, and can no longer judge of anything.

For the professor of physics, whose task is to appreciate sounds as a result of vibrations however produced, the case is quite different. Here there is no musical preöccupation. When we listen to a sound to learn something—and this is invariably our object—we may pay but little attention to its distinctness, since this is known from the first: what must be carefully listened to are the feeble sounds which always precede it, those which accompany it, and those which sometimes follow it. If we listen to the tone of a sound, we should only keep in view the detection of the mode of vibration, or the different sounds which may produce it. Finally, if we listen to two or to several sounds at the same time, it should merely be to appreciate their musical interval, or, to speak more strictly, their numerical relation; but as we can have an idea of their numerical relation only from their musical interval, it follows that the professor of physics is obliged to be cognizant of these intervals: this is the only musical knowledge he requires for all that concerns the appreciation of sounds; but of this he ought to be master, for if he have doubts respecting a single interval, he may deceive himself just as easily by an interval of ten notes as by one of a half-note.

Think of what immense resources the ear would procure us if, instead of often hearing noises, it always heard sounds; if, ever aware of what it hears, it could distinguish and separate many sounds where we imagine we hear but one; if it could appreciate the numerical relations existing between them; if it could recognize, by the intensity, the tone, and certain relations, what kinds of vibrations might produce them, what rank they hold in the harmonic scale—if they arise from a regular and easy division of matter, or from an irregular and constrained division; and, finally, whether they arise from the coincidence of two or of several sounds. Certainly we should then have reason to hope that the assistance of the ear in well-directed researches would not be of less importance in investigating the vibrations of liquids and of gases than the aid of the eye has hitherto been in the investigation of the vibrations of solid bodies.

But is it possible that education can render the ear fitted for such functions?

Ah! what may we not expect from this precious organ, whose least merit is to keep watch almost constantly, to bring under our observation and instruct us, without ceasing, concerning things that interest us, even when we do not think of listening to them!

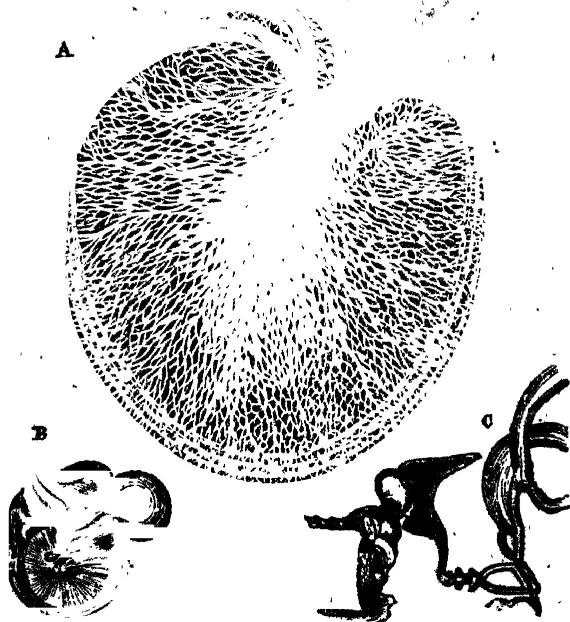


FIG. 434.—*Drawing made from the Microscope, by Mr. Lewis Aldous, of the Tympanum (or Drum) of the Ear,*

Showing its remarkable organization, and the number of blood-vessels which are spread over its whole surface. The smaller figures, B and C, represent the inside and side view of the drum, showing the small bones of the ear, viz., the *malleus*, or hammer; the *incus*, or anvil; the *stapes*, or stirrup; the last two bones being connected with a small round bone, called the *os orbiculare*.

Is its memory defective? Does not the peasant recognize the sound of his village bell thirty years after he has left it? Do not we recognize a person whom we have not seen for twenty-five or thirty years, and when the ravages of time have altered his personal appearance, by the sound of a single word that he pronounces? Has not the musician ever the sound of his tuning-fork diapason in his ear, notwithstanding the multitude of sounds which he hears incessantly, and which apparently ought to make him forget it?

Is its sensibility defective? If there be question of the sensibility which consists in appreciating feeble sounds, does it not hear the sound produced in the air by the wings of a fly with a degree of certainty sufficient to determine exactly the number of strokes of the wings made by the fly in each second of time? If there be question, on the contrary, of the sensibility whose limits are contained between the highest and lowest notes, here the latitude of the

ear is immense, since it appreciates with certainty all the sounds comprised between thirty-two vibrations in a second and ten thousand; and it may go far beyond this, as I proved by tuning, for M. Despretz, eight tuning-forks, forming an octave of notes, between sixteen thousand and thirty-two thousand vibrations in a second, or about two octaves beyond the limits of musical notes; and if I failed in tuning the octave which followed, it was doubtlessly from want of skill, for, although I failed in producing the intermediate notes, I succeeded in the octave of the last note, which corresponded to sixty-four thousand vibrations in a second.*

Is it less adapted to separate and appreciate the different sounds which concur for the production of any of its sensations? Assuredly not. When the leader of an orchestra hears a chord which is frequently formed by the concurrence of all the instruments placed under his direction, he not only appreciates the effect and justness of this chord, but he distinguishes separately all the notes which compose it, the sounds of the instruments which produce it, and the rhythm of the music under execution.

Is its delicacy defective in distinguishing the various species of sounds or noises that it hears, and in deciding what are the bodies which produce them? Does not a needlewoman distinguish by the sound whether it be silk or cotton that is torn? Is not the peasant aware, long before he perceives anything, whether the sound he hears is that of a diligence, a cabriolet, or a cart, and whether they be loaded or empty? Do not the blind recognize the ages of persons by the sound of their voices?

Is its precision defective in appreciating the relations which sounds bear to each other? Oh, in this respect what is the precision of the eye when compared with that of the ear? If we ask an architect habituated to linear measurements the relative lengths of two lines neither parallel nor situate in the same plane, should he err only by a thirtieth part, we are struck by the correctness of his eye; but to the ear a thirtieth part represents more than a quarter of a note. Now, a practised ear which hears two sounds can err only by a four-hundredth part, or about the forty-fifth part of a note.

Finally, is its promptitude defective in seizing sounds which pass with rapidity, and whose traces are lost in space? Far from it, since the preservation of the ear is chiefly due to its sensations and judgments being instantaneous. Let a sound last but a tenth part of a second, it is known and better

* When I accorded these tuning-forks, I travelled twelve times over the whole extent of the octave to find the six notes I wished to interpolate. On the first two occasions I distinguished nothing; I then caught the intervals in the following order: the fourth, the fifth, the minor sixth, the minor third, the major sixth, the major third, the minor seventh, the major seventh, and, with great pains, the major second. As I am a man gifted with a musical ear, but who does not understand music, I conclude that if there exists a natural gamut for the ear, which I believe to be a fact, it is the minor gamut, and not the major.

A propos of the gamut, I stated positively that it is not true, as musicians suppose, that a sharp note is higher than the flat note which corresponds with it. For a long time I successfully defended one of the numerous mathematical gamuts by means of experiments apparently very conclusive, when M. Barbereau, professor of harmony, took the trouble of coming to my house, for the express purpose of demonstrating to me that I had only viewed one side of the question. He agreed with me, in the first instance, that I was right when intervals were considered separately; but that, when they were considered as regarded melody, I was completely in error. To prove this, he took, on my sonometer, major and minor thirds, either so strong or so feeble as not to be endurable to the ear when taken by themselves; then, by means of melodies sung with much precision, he brought out these thirds, which I found, if not perfectly just, were at all events very tolerable. He afterwards made analogous experiments on the sixths with the same results. Thus, thanks to his kindness (for which I am sincerely grateful), I learned that in music, as in painting, it is *taste* and *sentiment* that decide what is *art* properly so called, and not geometry.

known than if it lasted for a minute; and if in this short and almost indivisible interval of time it hears simultaneously many sounds, it distinguishes them all, compares them all, and never confounds them.

But if the ear be thus gifted, as beyond all doubt it is, since the facts I have cited may be observed and verified every day, how does it happen that persons could have thought, or sometimes think still, of giving to it, as an auxiliary, membranes or any other kind of artificial ears? Does not a desire thus to aid the delicate sensibility of the ear resemble a wish to give light to the sun by a candle?

Let us learn to listen, let us accustom the ear to listen always, and to listen to everything. Let us practise it in the analysis of the sensations it experiences, and we shall find that all the faculties of the ear are developed by exercise, that several of them invariably become more perfect, that its delicacy becomes infinite, its precision absolute, its fidelity constant, even when our judgment deceives us, and when the aid it can afford us in questions of acoustics can only be limited by our skill in using it.

For twenty years I suspected these truths without being able to acquire sufficient proofs of them, and consequently without daring to give myself up altogether to the impressions of my ear, until the National Exhibition of the Products of Industry of 1849, which gave me an opportunity of becoming assured that the ear is exactly what I had imagined it to be.

During the *concours* for musical instruments, where I was present as a member of the central jury,* I listened to the instruments with my back turned, to avoid being influenced in any way; for although the makers' names on them were covered with numbered tickets, I still might have recognized several from having seen them either at the Exhibition or in the workshops, and thus my judgment might be warped. Vain precautions! From the moment a pianoforte maker had two instruments classified, and when I consequently became acquainted with his name, I recognized nearly all the various kinds of instruments he afterwards presented, from a sort of regularity or uniformity of defects in the precision; of the wind instruments, from a homogeneous sound of the instruments in general, but chiefly from certain shades of tone, which give to all kinds of instruments by the same maker a tolerably characteristic family resemblance, so that an attentive and practised ear cannot be mistaken when it compares them under the same circumstances.

I was in an excellent position for testing all the precious qualities I attributed to the ear, and opportunities could not be wanting. One day, while they were trying the wind instruments, I heard something unforeseen which astonished me, and which I could not comprehend. Fearing on the instant that my attention was not as great as the gravity of the circumstances required, I became troubled, the blood rushed violently to my head; but I recovered immediately, and my attention redoubled. Shortly after I saw and heard nothing of what was passing around me, with the exception of the subject which interested me. From that moment it appeared to me as if the sound produced by the fingers, the lips, and even the breath of the artists who were trying the instruments penetrated my burning ear to communicate to it the sensation of all I wished to hear. It appeared to me that the sensibility of my ear increased as

* I believe M. Seguier was the first person who proposed me to discharge this duty. I here record the testimony of my eternal gratitude to him for having powerfully contributed to make the ear known to

its tension became greater, and that it annihilated all my other senses by absorbing my whole existence. I imagined that I heard the tone of an instrument the instant the artist laid his hand on it to take it up. I thought I could distinguish the instruments made in the new or in the old establishments, or in those where the workmen are frequently or are seldom changed. I thought I could recognize instruments made expressly for the *concours*, or which were not of their ordinary mode of fabrication, although they were made in the establishment which presented them. I thought I could detect a difference in the tone and precision of the same wind instrument when it was cold or when it was heated by the hand of the artist. I thought I could hear each note accompanied by a harmonic sound, and preceded by another higher in the scale. I thought I could recognize the sounds I heard five years before under similar circumstances, when I was present as an amateur. I thought I heard,—I still listened. But we cannot fatigue the ear with impunity: the effort it had made had destroyed its sensibility, and I do not suppose that it can for a long time hence be submitted to a similar test.

Did I hear in reality all that I imagined I heard? Could the sensations I experienced arise simply from great nervous excitement, altogether unconnected with imagination? I doubted this at the time, but I am now convinced of the faithful judgment of my ear.

If all that I have just said suffice to show that the ear may be deemed worthy of consultation in acoustic questions, I shall doubtless be pardoned for tracing here, perhaps, in the form of a lecture, the path to follow for its education; but, before I proceed further, I wish to rectify an error to which too general credence is given.

People generally imagine that a good ear is by no means common, and frequently persons are impressed with an idea that they have no ear or a false ear. Let them make their minds easy on this subject: bad ears are much rarer than good ones. Among all those on which I have experimented—and the number is great—I never met with one even defective. I found some little or not at all exercised, some practised more or less, some more or less sensible; but all without exception were susceptible of acquiring a high degree of precision and considerable delicacy by education. Now, is it an indifferent matter at what age we commence the education of the ear? Unfortunately not. In infancy the ear adapts itself to all the exercises we make it undergo; its progress is rapid; its sensibility even increases by habit; while at the age of five-and-twenty the ear is less obedient, its progress is slower: it can doubtless still arrive (like my own ear, whose defective education commenced at this age) to a certain degree of precision and delicacy; but frequently it will meet with difficulties that it cannot overcome. It would, therefore, be most desirable, for the interests of science, and even for that of musical art and the fabrication of musical instruments, that in all colleges and schools the ear of the pupils be practised, not precisely to make them musicians, but to teach them to listen and to understand what they hear.

For the purpose of hearing, it is useless to listen. In its normal state the ear hears constantly, and hears everything. To distinguish and appreciate what we hear, it does not suffice to listen, even when the ear is practised; we should know how to listen, which is a very rare acquirement. When the ear is struck by any sound or noise, its attention is generally directed to the entire sound at once; it thence follows that the general result is heard without any distinction of the parts which compose it, and that we become acquainted with

the effect, but not with the causes which gave rise to it. This is so exactly true, that if we address the following observation to the majority of performers on the pianoforte, "The bass notes of certain pianos are disagreeable; each note is accompanied by a minor seventh or a major ninth," they will tell us, "I can hear nothing of the kind."

That is not true; for when we strike the offending notes to make our remark more evident, they will allow that they heard all just as we did ourselves, and sometimes even with sufficient distinctness to prove disagreeable to the ear. Thus, then, a practised ear, from not knowing how to listen, may sometimes not distinguish sounds of a disagreeable nature. In the same way, when the greater number of musicians test the qualities of an instrument (supposing them neither preoccupied concerning its origin nor by whom it was manufactured), what they exactly appreciate is the relation which the instrument bears in its *ensemble* to another with which they are already acquainted; but as to the instrument itself, it remains unknown to them; whatever its defects may be, they pass unperceived, if these same defects are usually met with in similar instruments. They hear the tone, but they do not remark the relation of the harmonic sounds to the notes which they accompany, nor the sounds of the wood, strings, copper, &c., which characterize the tone; and this arises from their not knowing how to listen, for they hear them all.

On the Education of the Ear.

The first thing to be done when we commence the education of the ear is to teach it how to listen. From the commencement, we should habituate ourselves to fix all the attention of the ear on a single sound; thus, when we hear several sounds or noises simultaneously, we should listen but to one; when we hear two sounds, one loud and the other feeble, we should listen only to the latter, and try to be deaf to the former. We should habituate ourselves to listen in what manner sounds begin, and how they end; and also to lend the ear much less to what we hear than to what we imagine we do not hear, and never to listen more than an instant to the same thing. For the moment, these exercises will not teach us much; but we should constantly practise them until from habit they become familiar.

While we are engaged with these exercises, we should teach the ear to distinguish musical intervals. This generally appears somewhat startling, as the greater number of students learn music for three or four years without being acquainted with them, and for this excellent reason—that they receive no instruction on the subject. By beginning the study of musical intervals at the age of twenty-five years, it requires six or eight months to become well acquainted with them when we devote to these studies one hour each day. This is something, I am aware; but it is also something to have a practised ear if we should require it.

As to the method to be adopted in the study of intervals, I think I cannot do better than to indicate that followed by M. Duchemin, director of musical instruction in the asylums *(salles d'asile)* of Paris, by reason that the results which I witnessed, when he tried his method of musical instruction at my house, left nothing to be desired.

M. Duchemin, setting aside all ideas of notation, commences by demonstrating to the pupil, by means of any musical instrument whatever, the interval of a note and that of half a note. After the pupil has been sufficiently instructed in the distinction of these intervals, he makes him listen to the interval

of a note and to that of a major third. He next makes him compare the major third with the fourth, and thus successively all the major intervals of the same octave. He then returns to the point from which he started, and makes him compare the major with the minor intervals. When the pupil is acquainted with all the ascending intervals, he recommences the same exercises as above, but in descending. Finally, when the pupil has compared all the intervals by two and two, M. Duchemin makes him listen to isolated intervals, either ascending or descending; at first those comprised within a single octave, afterwards within two octaves, &c.

If the knowledge of musical intervals thus obtained be sufficient for the musician, it is not so for the professor of physics. It does not suffice for him to be aware when an interval is true or false, or even when it is too great or too small; he must be capable of estimating almost exactly to what degree it be too great or too small. Neither does it suffice for him to be capable of comparing the notes produced by musical instruments; for, as sound to him represents every sensation of the ear that arises from any vibratory motion whatever, he will hear them of every kind, as regards their tone, their intensity, their duration, their sharpness, &c.; he will even frequently be forced to separate and to compare sounds which have neither the same tone, intensity, or duration, and he then requires a great accuracy of ear and long experience to keep free from errors. It becomes, therefore, necessary to resume the study of intervals; but now no instructor is required, and some of the experiments may be performed without seriously occupying our time.

At present each interval is to be compared with itself, by taking it true in one case and more or less altered in the other. For this purpose we make use of a sonometer, divided so as to enable us to take exact intervals, and at the same time to make known to us the numerical difference existing between the true interval and this same interval when altered. (My differential sonometer is well adapted to this purpose; indeed, I called it by this name because, from the date of its first construction, I used it for this object.) And as it is required to hear the two sounds of the same interval in the shortest possible space of time, and to hear them often repeated simultaneously, to accustom the ear to this sensation, we begin by tuning to unison the two strings of the sonometer, to enable us to take, by means of movable bridges, the first note on one string and the second on the other. Then we compare the true interval at first with the interval altered to the maximum, that is to say, about a quarter of a note either higher or lower, and we continue the comparison by gradually diminishing the difference to zero, but always commence the experiment by listening to the true interval. It is not with a fiddle-bow that we sound the strings in these experiments, but with the fingers, and always feebly, by reason that we can better appreciate sounds that are low and of short duration than we can those which are loud and long-continued.*

We can easily comprehend that by means of these experiments the ear not only learns to estimate the relation of two sounds with tolerable precision, but, moreover, it becomes habituated to the most rigorous exactness.

We have hitherto only learned to recognize the intervals of notes which are very distinct and always of the same nature, since they were produced

* The sounds that the ear appreciates most easily are those comprised within the diapason of the human voice: those which it judges best are sounds of a feeble but invariable intensity; for, strange to say, the ear, in other respects so just, is always inclined to believe that a sound becomes lower when its intensity increases.

by the same instrument. This is not enough; we must also be able to appreciate the intervals of sounds which have but little distinctness, and even those which exist between two sounds of different kinds. For this purpose there is no further necessity for instruments or for regular studies; it suffices to consider the subject at our leisure, and to seize on such opportunities as may present themselves. For example, if we sit alone at table, we may compare the sound of a glass or of a decanter with that of a bottle. If we have at hand two bottles unequally filled, we may blow on the edges of their apertures: the sounds which result will be feeble, but will still be very appreciable even to unpractised ears. At our fireside, we may compare the sound of the fire-shovel with that of the tongs. In a word, according to the circumstances in which we may be placed, we can use for this investigation all objects capable of yielding sounds. By employing daily some of our leisure moments with these exercises, apparently very innocent and futile, the ear will insensibly become accustomed no longer to hear *noises*, but always to hear *sounds*, and sounds whose mutual relation it will perfectly comprehend.

So long as sounds have the same tone, no matter how short be their duration, how defined or even sharp they may be, their relations can always be observed with tolerable ease. Everybody can recognize a gamut resulting from the noises produced by eight pieces of wood (cut until they accord with an octave of musical notes) when they are thrown on the floor, although the tone resulting from the fall of any single piece be inappreciable to musicians; but this is no longer the case when the sounds have different tones, especially when they are not well defined: in these instances it is extremely easy for an ear, unless it be highly practised, to be deceived by an octave, and even to confound the octave with the fifth when the interval exceeds three octaves.

Finally, there remains something to be done which is neither the least important or the most easy, and this is the exercise of the ear in the analysis of sounds. It is no difficult matter for a musician to analyse a chord, because, in the first place, all chords are familiar to him, and, in the next, because the notes of which it is composed are always very distinct, and are produced by instruments with whose tones he is acquainted; but to analyse a chord or mixture of sounds when we often imagine we hear but a single one—and, moreover, having no *data* to guide us in our researches for those we imagine may accompany it, we propose to ourselves not merely to discover the relations existing between them, but still further to determine their origin, as well as the causes which gave rise to them—is a very different affair. Here the habit of hearing sounds will no longer suffice; we must know how to listen to them, and have studied them.

All that I can do here is to indicate the exercises which should be adopted for learning to distinguish one or several feeble sounds when they are connected with a louder one. I shall then enter on some considerations respecting sound, where, among the observations I shall have occasion to make, may be found certain *data* which will frequently be of use in the solution of questions of this nature.

For the first exercise we select a note, neither too low nor too high, and as pure as possible, as, for example, that of an open organ-tube between the notes *ut* 2 and *ut* 3, or that of my tuning-fork mounted on its stand. To this sound we add another well known beforehand, but differing in tone and by an interval either true or false, such as a note taken at hazard on a violin or on a plate or blade of metal. While we hear these two sounds simultaneously,

we should listen only to the higher note, which should be gradually weakened, by removing it to a distance, or by other means according to its nature, until we cease to distinguish it, which ought only to be when we cease to hear it. We may perceive that this sound is still very distinct to the ear so long as we can take its unison on the sonometer. We should recommence this exercise, always changing the higher note, until the ear is sure of the interval, no matter how feeble the tone may be.

We may renew these experiments, using, if we please, the same instruments as we did before, provided we change the lower note; but now the higher note that we add ought to be unknown—that is to say, it should not have been heard alone previous to the experiment; it should be, moreover, continuous and feeble in proportion to the lower note, that it may be placed precisely in the conditions of the harmonic and other sounds which always accompany the principal note. The two notes being thus heard, we should try to appreciate their interval, and at the same time the tone of the upper note.

When we have attained the instruction requisite for analysing a mixture of two sounds differing in tone and intensity, we should employ the same means in learning to analyse a mixture of three sounds; and here we may stop. The habit acquired of listening will accomplish whatever remains to be done; for one of the attributes of the ear being to hear always without any participation of our will, it follows that, having once contracted a habit of listening, it listens almost without our being aware of it. Thus, without thinking of it, when we hear a drinking-glass struck by the blade of a knife, we distinguish three sounds—the fundamental note and the first harmonic, whose interval varies, according to the form and proportions of the glass, from the minor sixth to the major tenth, and, besides, the second harmonic, which is very feeble and much higher.

When we hear a string of moderate length resound, we may distinguish a suite of harmonics, and remark that these sounds vary according to the portion of the string on which we operate, and the mode we adopt to produce the vibrations.

When we hear a drum, we remark first a low, uncertain, and confused note, which is that of the air it encloses: then a series of clearer and better defined notes, announcing a more easy mode of vibrations; this is the fundamental note of the membrane and its harmonics, among which we frequently distinguish a tolerably agreeable ninth or tenth. We may besides remark a great number of harmonics, very high in the scale and of short duration: they are produced by the action of the chords on the inferior membrane; and, finally, we recognize, by a sort of metallic tinkling, the sound produced by the brass cylinder of the drum.

One word more on the analysis of sounds. When a tuning-fork is mounted on a hollow stand which yields a note in unison with it (as I have constructed this instrument), it is easily put in action by the slightest vibratory motion which the air contained in its stand may receive from any extraneous sound; but, as substances vibrate sympathetically only from the influence of their unison, it follows that the tuning-fork is deaf to all sounds excepting its own, to which it instantly replies with more or less energy, according as the sounds are more or less identified, as they are nearer or farther from each other, and as the sound is more or less intense. If, then, a tuning-fork thus mounted be placed in the proximity of any sound accompanied by a harmonic in unison with the tuning-fork, this latter, by vibrating, instantly announces the fact.

Far from me I reject the idea of proposing such a method of supplying the ear. I know the ear too well. Nevertheless, I have used it, and often with success, but only in cases where I suspected a sound to be accompanied by its upper octave, which I was unable to distinguish, less from its weakness than from its perfect consonance with the principal note.

It was by this method that I found the notes of the human voice from the chest are always accompanied by the upper octave and by the double octave.

Considerations on Sound.

There exists no simple sound; all, without exception, are accompanied by a mixture of other sounds more or less appreciable to the ear, varying according to the number of those which compose it, to their respective relations, and to the mode of vibrations which give rise to them, and according to the size, form, and description of matter which produces them. Furthermore, if the sounding body, from its size, shape, or nature, be capable of easily yielding two sounds of the same description—I mean, arising from a similar mode of vibration—we never hear the lower sound without its being preceded by the higher, except, perhaps, when its vibration is induced by the influence of a unison. And if it can readily yield many sounds of the same kind, the first harmonics, like the fundamental note, will always be preceded by other harmonics higher in the scale.

The series of experiments which led me to these observations are the following:—In the second edition of my catalogue I inserted a few words respecting a very remarkable experiment of M. Delezenne on strings in vibration, and of the conclusions drawn thence by M. Duhamel and by myself.

M. Delezenne showed me, in 1842, that it is impossible to make a string sound by drawing a bow across its centre. M. Duhamel, to whom I mentioned this circumstance, suspected that, in a string which yields the fundamental note, the first harmonic oscillates, and that the note cannot be developed, because the bow prevents the motion when applied to the middle of the string. To verify his hypothesis, M. Duhamel tried to make the string resound by means of two bows moving in the same direction, and placed on the right and left of the centre of the string: no sound resulted. When, on the contrary, he drew the two bows across the same portions of the string, but in opposite directions, the fundamental note was instantly developed, and accompanied by the first harmonic. Although this ingenious demonstration did not admit of a reply, yet I did not long remain convinced. I could not comprehend why the first harmonic was more necessary to the development of the fundamental note of the string than any other harmonics higher in the scale which we commonly hear during the entire duration of a sound. I then, in accordance with the established custom, abandoned the ear for the eyes. I endeavoured, on the monochord of Savart, to make the string yield the fundamental note by drawing the bow near its centre. I succeeded, and I saw two chords or divisions, with a node of vibration in their centre. M. Duhamel was again right.

I afterwards operated on the string near the other harmonic divisions in succession, and always procured the fundamental note. Thus, when I operated near the third of its length, I saw three chords or divisions, each with a node of vibration at the third of its length. By operating near the quarter of its length, I saw four divisions; near the fifth, five; and so on. Then, laying aside this instrument, which yields no sound, to use my differential sonometer in its stead, and to appeal to the judgment of the ear, I recognized, in fact, that by

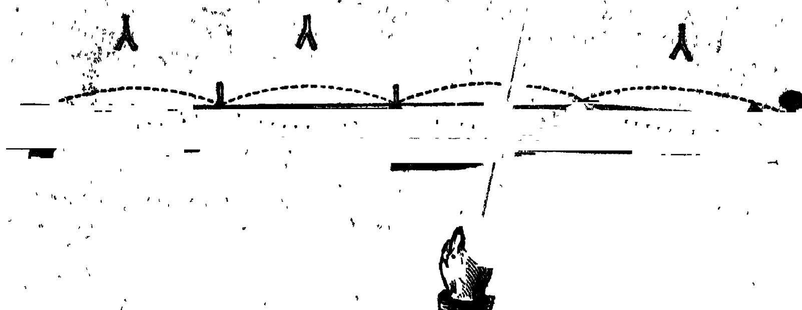


FIG. 435.—*The Monochord*,

Showing the ventral segments, or those portions of the strings which are the most violently agitated, and therefore throw off the paper riders, whilst they remain quiescent at the nodal points.

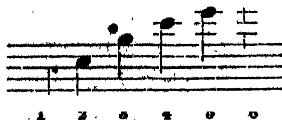
acting on the string near the third of its length, we hear with almost equal intensity the twelfth and the fundamental or key-note. When we act near the quarter of its length, we hear the double octave; near the fifth, the major seventeenth, &c. And what is worthy of remark, the harmonic always precedes the key-note.*

From these experiments we find that the harmonic which of necessity accompanies the fundamental note is not always the first, but is that which corresponds to the nearest division to the part acted on. It hence results that a string perfectly free from all foreign influence cannot be made to resound by the bow, not only when we act on its centre, but still further when we operate on any of its harmonic divisions, as may be shown by my apparatus for the longitudinal vibration of strings.

All that has been stated with respect to the emission of the fundamental note of a string vibrating transversely is applicable to harmonic sounds, at least within the limits of possibility—that is to say, all the experiments made on the whole string yielding the fundamental note may be repeated on a portion of it yielding a harmonic note, only the phenomena will be less sensible, by reason that the portions of the string which remain free influence in a greater or less degree that which we act on; and, besides, the notes are pro-

* The notes called harmonics are thus called from their accordance and harmonious relations to each other. The number of their vibrations are to each other, when produced in tubes open at both ends, as the natural suite of numbers, 1, 2, 3, 4, &c. Thus, 1 representing the fundamental note, the first harmonic to this note will be its upper octave; for the vibrations of the upper octave of any note are always double those of that note. The next harmonic vibrates three times as often as the key-note; the fourth, four times, &c.

These harmonics can easily be produced on the German flute. Thus, when all the holes and keys of the flute are shut, if it be made to sound, and the force of inflation be constantly increased, it first yields *ut* the key-note, next *ut* the octave, next *sol*, next *ut* the double octave, next *mi*, and, afterwards, *la*.



The harmonics produced by a tube closed at one end are as the numbers 1, 3, 5, 7, &c., which evidently accord with each other, as we find them all in the harmonics produced in open tubes.

portionately less appreciable to the ear, as they are higher and more feeble. Thus, for example, if we try to sound the first harmonic of a string (even when isolated as much as possible) by lightly placing a finger on the middle of the string and drawing the bow across the centre of one of the halves, instead of hearing nothing, as in the former instance, we shall hear this harmonic a little, although it be imperfectly articulated, because, the other half of the string remaining free, there is nothing to impede its division, if not into two, at all events into three portions, and it may consequently yield some sort of sound. In the same way, if we act on one of the halves of the string near its centre to make it resound, there will be no reason why the first harmonic should be accompanied by the second rather than the third, since there is nothing to prevent these divisions in the other half of the string. But, no matter what be the circumstances which favour the development of this sound, we never hear it unless it be preceded and accompanied by a higher harmonic note; and this is equally true as regards the third and other harmonics higher in the scale, so long as these notes are perceptible to the ear.

We have said enough on this subject. It suffices to have demonstrated here that a string on which we act transversely can resound only on the condition that it can yield at least two transverse sounds, of which the higher will depend on the part acted on, or on the mode of inducing the vibrations.

Every string which vibrates transversely between two fixed points vibrates longitudinally at the same time: this is evident from the fact that it cannot deviate from a straight line without being lengthened, or return to a straight line without being shortened. The sound thence resulting is almost insensible in musical instruments, and even in the sonometer, because the bridge being incapable of arresting the longitudinal vibratory motion, it is transmitted to the portion of the string beyond it, which renders this sound very variable and prevents its development. It may sometimes, however, be heard, though considerably altered, in the *la* of the violoncello, as persons who learn to play on this instrument are well aware, although they cannot account for it. It is the sound which, when well articulated, is known in the language of musicians by the term *canard*.

When the string, on the contrary, vibrates between two fixed points, as in the apparatus for longitudinal vibrations, then when we act on it with the bow, or when we strike it, the longitudinal sound accompanies the transverse one as long as it lasts, and, if we listen attentively when we sound the first harmonic transversely, we shall hear equally the longitudinal sound of half the string.

Independently of these two different modes of vibration, every string which vibrates tranversely executes a third, which is inseparable from the two others.

Let us hang on the middle of a string a very thin brass wire, bent like the figure 8, supporting on one of its rings a little cone of paper, while the other encloses the string without pressing on it; let us then make the string vibrate transversely, either with the bow or by striking it, and we shall immediately observe the cone to turn round with an extreme rapidity, then return and revolve in the opposite direction, and change in this manner ten or twelve times, if it be lightly constructed. And, to observe this phenomenon, it is by no means necessary to bring out the key-note of the string: the cone will turn in the same way at the ventral points of vibration of the first, the second, and even the third harmonic; and if, instead of one cone, we suspend two on the string, we remark that, when they are placed on two consecutive divisions, they turn in opposite directions.

Now, to determine this phenomenon, it is evident that the string must, in vibrating, assume a rotatory motion, for the cone turns round it; and also that this rotatory motion arises from a twisting of the string, for the cone revolves periodically in opposite directions.*

It results from all that has been said, that a string which vibrates transversely is forced to execute at least four different vibratory motions, viz., two transverse, as I have already explained, one longitudinal, and an alternating rotatory motion. Now, if we add to these the different accidental vibratory motions which arise from various transformations, that is to say, those which give rise to a multitude of harmonics of all kinds, which we invariably hear when the string is long, we find that a string of medium length which sounds transversely may often simultaneously execute ten or twelve different vibratory motions.

If the simultaneous concurrence of several different vibratory motions be indispensable for the production of sound in a string, this concurrence is not less essential to the production of sound in any other substance, no matter what be its form or nature; for although I have for eight years sought to discover a simple sound, yet I have found none: all the sounds I hear are preceded and accompanied by one or more harmonics, arising from one or from several modes of different vibrations, whose relations with the principal sound vary according to the nature and form of the vibrating substance, and also frequently from the point acted on, and the method used to excite its vibrations. From thence is chiefly derived the variety of tones produced by substances which vary in form and nature, as also the difference which frequently exists in the tone of the same sound produced by the same substance when it is acted on at different points or set in vibration by different means. In solid bodies a sound produced by a shock has rarely the same tone as when the sound is produced by a bow, because the action of the bow often prevents the spontaneous development of certain harmonics from transformations of motion, while, at the same time, it gives rise to others, which persist as long as its action is continued, as is exemplified in the case of strings. In the columns of air which only yield harmonics, as in the French horn, the trumpet, the trombone, and all the instruments *à piston*, the tone is very different from that which we observe in columns of air which yield the fundamental note, as in the flute, the clarionet, the ophicleide, &c.; in the first place, because the *embouchure* has a great influence on the tone, and, next, because in the former instruments the vibrations are only longitudinal, whereas in the latter they are mixed, as we shall find hereafter; consequently, the same note taken in the two different cases may not be accompanied by the same harmonics.

Thus, when we wish to ascertain the different vibratory motions coexisting in a vibrating substance, and when we judge merely by the ear, we must necessarily take into account the manner in which these vibrations are excited.

* This fact explains what I was long in search of, namely, why the air enclosed in a violin resounds under the action of the bow. Savart, after having demonstrated that, when a system is put into a state of vibration, the vibratory motion is propagated throughout all its parts parallel to the axis of the motion impressed on it, was already occupied about this question, and, after many ingenious experiments on the sounding-post of the violin, he came to the conclusion that its function was to transform into normal vibrations the tangential vibrations which the bow impresses on the bridge. But when we suppress the sounding-post of a violin, if it have less sound than it had before, it has still a hundred times as much as when we suppress the under board of the violin ("*fond du violon*"), as we may easily believe without needing to repeat the experiment. Then, if the enclosed air still acts with energy, it is evidently because the rotatory movement of torsion in the string renders the transverse vibrations sometimes tangential to the bridge and sometimes perpendicular to it.

It would likewise be necessary in experimenting to have a locality perfectly adapted to this kind of observation, and with whose acoustic properties we should be well acquainted. Questions connected with sound are already so complex that we cannot take too many precautions to prevent any disturbing causes still further complicating the phenomena.

In experimenting in a room, I have often observed that a double reflection suffices to produce beatings (*battements*) with the sound or with one of its harmonics, so as to excite a suspicion of two sounds nearly identical where there is only one.

I also discovered that a certain intensity of a transverse harmonic may be attributed to longitudinal vibrations, when this intensity is merely due to a coincidence of vibrations between this harmonic and a subdivision of the air or any other matter contained in the room.

It again happens that we may imagine we cause the air enclosed in the "*caisse*"—the body of the violin—to resound, while in reality we only make sound a harmonic of the room; or that, in seeking to communicate a vibratory motion to a solid or liquid, we determine in a contiguous mass of air a sound totally different from that we imagine we hear.

Very frequently also we are exposed to the chance of allowing many feeble sounds to escape us, which would be very appreciable to the ear if it were not unceasingly troubled and incommoded by noise from without, which we imagine we do not hear, because we hear it always.

And yet what have we done, up to the present time, to prevent the causes of these errors, and probably many others that are still unknown? Nothing that I know of. It would even appear that they were never given a thought. People experiment indifferently in one place or another, which, to speak the truth, imports but little, since we are aware of none suited for acoustics.

Well, I ask, if, before we endeavour to penetrate this labyrinth of errors and deceptions, it would not be reasonable to turn our steps backward, to act as if we believed we knew nothing of sound, and commence a serious investigation of all the phenomena that sound may offer us in space, whether limited or indefinite, when freely transmitted through the air or through an obstacle either solid or liquid, when partially or totally reflected, &c.; not merely in a scientific, but also in a practical point of view, since the object of every science ought to be its application? Is it not, in fact, desirable that the spectacle so humiliating to science should cease, of all the fruitless or ridiculous efforts made in architecture every day to remedy acoustic defects which could neither be avoided nor foreseen? Is it not deplorable to witness that in Europe there does not exist a passable parliamentary chamber or hall of audience that is not due to hazard? Let it be distinctly understood, it is not the ignorance of the architects that I accuse: they may well be allowed to be ignorant of what philosophers do not suspect. Neither shall I reproach musicians with heaping together a mass of artists in a concert-room, with whose acoustic properties they are unacquainted, with a view of annihilating by a volume of sound, which they cannot obtain, the defects they presume to exist in a room built at hazard; no, they are sufficiently unhappy in being obliged to hear to the end the *charivari* they endeavour to render harmonious.

The *savants* are the persons responsible for the greater number of these errors, for Art expects to derive all her light from Science. Therefore, it is to them I address myself to support a petition, which I do not make (for I never make any), but which I think would be favourably received by the govern-

ment, if it were presented and supported by the eminent professors of physics by whom France is honoured.

PROJECT OF STUDY CONCERNING THE ACOUSTICS OF PUBLIC BUILDINGS.

The means I propose (unless better be offered) to endeavour to resolve the questions of acoustics concerning public buildings, as well as many others which at the present day check the advance of science, consists in constructing, in a locality properly chosen, a deaf-and-dumb room, where no sound could penetrate without the will of the experimenter, and whose walls should be at first covered internally in such a manner as to reflect no sound. If it were possible to satisfy this condition, which appears to me not to be doubted, it is evident that this chamber would possess no sonority, since the enclosed air would vibrate as it would in unlimited space, and consequently only act as a vehicle of sound. There, exempt from all noise, from all reflection, in a word, from all disturbing causes, whatever was heard would be understood.

Passing on to researches concerning the transmission and reflection of sound in a limited space, we should at first assure ourselves that no node of vibration exists in the room thus prepared, at least to any sensible degree. Then, stripping the covering from the ceiling, which I suppose flat, for the purpose of obtaining a reflecting plane, we should seek in the air the position of the nodes of vibration, to which various sounds produced in different parts of the room might give rise, and we should observe, as we advanced, that sound is carried farther with the reflecting ceiling than it was in the first instance. We should afterwards uncover the floor and the four walls in succession, observing at each new modification the nodes of vibration produced in the air by the same sounds proceeding from the same places, and noting carefully the state of things at the moment the sound begins to lose its purity, that is to say, the moment the sound begins to remain in space after the cessation of the cause which produced it; for that a sound may be distinct, it is not enough that it appear intense; it must above all be clear, especially in speaking.

We should next replace everything as at first, except the ceiling, which should remain uncovered, and be lowered by one-half its original height (that is to say, we should have a temporary ceiling constructed, which would only require a moderate solidity); then we should remark, in the first place, that at equal distances the same sounds appear clearer and more distinct than when the ceiling was more elevated, as we ought to expect, since the reflected sound traverses a shorter distance, from the angle of incidence being greater, and for the same reason the reflection is more complete. We should afterwards repeat the experiments in analogous cases for the determination of the nodes of vibration; then we should again uncover the floor and walls successively and in the same order as before, and repeat at every change the series of experiments we had already made under similar circumstances.

There is no doubt that after this first investigation we should become perfectly acquainted with all the acoustic properties connected with a regular prismatic space, having sides of an infinite resistance, at least for sounds whose intensity and whose extent of sonorous wave do not exceed that of the human voice.

Let there be now constructed within this chamber a second chamber, with slender sides about half a yard distant from the walls of the first, in order to isolate it completely, and to permit a free circulation of the air between the sides of the two chambers for the experiments to be made there.

Let us recommence in this new chamber, where the reflections will be only partial and confused, the series of experiments made already in the other, noting the length of the sonorous wave and the intensity that the sound has when it ceases to possess all the clearness we may desire, as also the influence that re-covering the walls of the first chamber may exercise on the second, and, in a word, all the observations that such a situation would give us an opportunity of making.

After this second operation, there would remain for us to study carefully the influence that might be exerted on the acoustic state of the room by currents of cold or heated air, or by air in a dry or moist state, proceeding from any particular part of the room; also the influence of apertures, their situation, the nature and resistance of their enclosing sides, and, finally, of the furniture, &c. But the greater portion of these investigations could be made almost everywhere, and at a trifling expense, since we should possess certain *data*, which would enable us always to say, "If such a room had not apertures, it would be so and so; if such another was furnished, it would be so and so," &c.

I shall probably regret not having entered more into detail—not to have mentioned a number of experiments to be made on reflection, produced under different incidences by rough or polished surfaces—to have said nothing of the relation which should exist between the resistance of the reflecting plane and the length of the sonorous wave—and, finally, not to have given sufficient development to my idea of making felt all the importance of my proposal, both in a scientific and practical point of view. Perhaps I shall even have to regret not having said enough to render my meaning perfectly clear; but I have already advanced far beyond my subject.

Here M. Marloye concludes his very original and important remarks, which he modestly hints are lengthy, but necessary, because all other acoustic and musical experiments and instruments are useless without the exquisite organ of hearing.

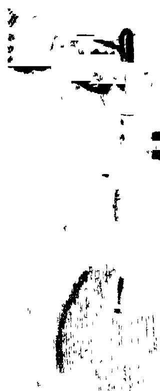


FIG. 436.
The Bell shaken or rung in a spherical Glass exhausted of Air.

If it be once clearly established in the mind that sound is produced by the vibration of the air, it would be expected that in the absence of this medium no sound could be obtained; hence the simple experiment of placing a bell (with certain precautions to check the conduction of sound by solid conductors) in a vacuum.

With the exception of a very few tremblings, which will find their way (leak out, as it were) through the points of suspension of the bell, the sound is entirely destroyed by the removal of the air from the interior of the spherical glass vessel.

It is evident that musical and all sound-producing instruments, and the vocal organs, must be surrounded with common air or other gaseous matter.

Hydrogen gas presents a remarkable feature in this respect, as it entirely alters the sound of a bell enveloped with it; in fact, it renders the bell soundless, and merely records the thumps of the clapper, and even this might be prevented by placing the bell apparatus (such as that used by the telegraph

companies) on a bad conductor of sound. It is usual to account for this almost magical effect on the sound of the bell by the lightness of hydrogen gas. No doubt this has a great deal to do with it; but there are vibratory powers which will affect this gas, and cause it to emit the most piercing notes. We have a proof of that in the vocal organs; for, when a small quantity of hydrogen is inhaled, the pitch of the voice is raised in the most ridiculous manner—sopranos fairly screech, and as to bass voices, they become sadly depraved and degraded into the thin treble of senility. Thus it would appear that as the exquisite particles of ether require a vibratory power of millions of millions of movements to occur in a second, so reason would suggest that, as hydrogen is the lightest known form of matter, there are few musical instruments, except the vocal organs, wind instruments, and organ-pipes, that can set up vibrations which will communicate themselves to this gas. A regular series of experiments with every kind of musical instrument caused to play by or in hydrogen gas may determine this question, and the writer proposes to try them, and will report the results in due time.

Every musical instrument is accompanied with, and does set up, a tremulous motion felt in an orchestra on the backs of the seats against which the singers may be leaning.

These impulses set up waves in the air, just as a constant series of blows delivered from a brass ball upon the surface of smooth water produces waves.

Sir C. Wheatstone's wave apparatus admirably demonstrates the mechanism of those regular disturbances of the air which resolve themselves into waves.

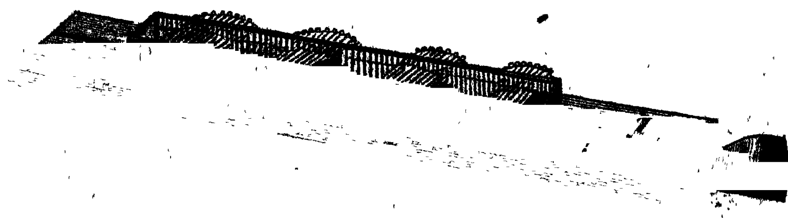


FIG. 437.—*Wheatstone's Wave Apparatus.*

The beads attached to the wires can only move in a vertical plane, and yet, by thrusting under them sliders of wood cut in the form of waves, the spectator has suggested to him the idea that they are moving bodily from one end of the framework to the other.

There is no test so delicate or so well adapted to show the transmission of vibrations and physical disturbances of the air as certain flames, such as those used in the experiments of Mr. W. F. Barrett.

"Three years ago* (December, 1865), whilst engaged in some acoustic experiments, this gentleman observed that every time a shrill note was produced a tall, tapering gas-flame in his vicinity was singularly affected, the flame shrinking every time the note was sounded. That observation led to further experiment and inquiry, the result of which has been the discovery of the conditions of success for obtaining flames sensitive to the slightest sound.

* Lecture delivered before the Dublin Royal Society by Mr. W. F. Barrett. "Chemical News," May 8, 1868.

Some months after the above observation, Professor Tyndall took up the subject, and, having largely added to its interest and importance, offered an explanation of the phenomenon in a lecture delivered at the Royal Institution, in January, 1867. At this lecture the discovery was first published, and the name given to 'Sensitive Flames.' Subsequently Mr. Barrett proposed a fuller explanation, and discovered that not only flames, but all gases, could be rendered extremely sensitive to sound—the track of the gas being marked by mixing it with smoke.* This historical notice would be unjust without referring to an observation made ten years ago in America by Professor Lecomte. That physicist had noticed that certain sustained sounds in an instrumental concert caused a very perceptible movement of the ordinary gas-flames in the room. This observation is really the germ of the more wonderful effects afterwards independently discovered by the lecturer. Though Professor Lecomte was the first to publish the fact in 1858, it appears that, previous to this date, artisans had frequently noticed the phenomenon as resulting from the shrill sounds of their work; and several musicians have informed the lecturer that the same effect has been one they have commonly observed.

"Turning now from scientific history to experiment, the lecturer showed various kinds and degrees of sensitive flames. First, a 'batswing' flame, which, under the ordinary gas pressure, moved slightly at the sound of a whistle, but thrust out long tongues of fire when the pressure was increased by urging the gas from a holder. This increased pressure was always necessary to obtain the more sensitive flames, for a reason that will be understood directly. A jet of gas, issuing from a V-shaped orifice, was shown to be quite insensible to sound until the flame reached a height of 10 or 12 inches, and then, at the sound of certain high notes, the flame shortened and spread out into a fan-shape. Whistling to this flame in one key had no effect, while in another the effect was very marked. Playing an air upon a so-called bird-organ, the flame selected the high notes, and promptly shortened at their recurrence.

"The probable cause of the sensitiveness of these flames was then alluded to. The impact of air evidently had nothing to do with the phenomenon. This was strikingly shown in the following experiment: By tapping a membrane stretched over the mouth of a large tin funnel, a puff of air could be driven with such force from the narrow extremity that a candle was easily extinguished some 12 ft. away. Directing this puff of air against the sensitive flame, it was seen that the flame moved violently, but was utterly unaffected when the puff was driven either to the right or left. This should also be the case if in former experiments it were the impact of the air, and not the sound, that produced the effect. But it was at once seen that when the lecturer whistled, at the same time slowly turning round, the flame still continued to shrink, and was almost as powerfully moved when the back was turned to the flame. The effect, then, is solely produced by the wave-like to-and-fro motion of the sonorous pulses. As first indicated by Professor Lecomte, a gas-flame to be sensitive has to be brought near its point of roaring; it then stands, according to Dr. Tyndall, as it were on the brink of a precipice, over which the sound pushes it. Agreeing with this explanation, that a sensitive flame is a body in a state of unstable equilibrium, the lecturer supplemented it by comparing the flame to a resonant jar, the flame, as was proved by a moving mirror, being in a state of rapid isochronous vibration when under the influ-

* "Philosophical Magazine," March and April, 1867.

ence of external sound. The actual shrinking of the flame was due to an increase in the velocity of the current of gas, which was possibly brought about by an external sound throwing the pipe that conveys the gas into a state of vibration, which would thus narrow the channel of the gas passage—the change in the aspect of the flame being largely modified by the shape of the burner."

At the Polytechnic, it was shown by the writer that the clanking of a chain in the gallery of the lecture-room affected, at a distance of 50 ft., the sensitive flame burning from a jet made of glass tube $\frac{1}{8}$ of an inch in diameter, and drawn out to a point by the glass-blower of the Institution.

The writer obtained nine or ten glass jets that answer the purpose remarkably well; but the pressure of the gas burnt must be high, that used being equal to 2 ft. of water, or about 1 lb. on the square inch.

The sensitive flame alluded to was wholly insensible to the musical notes of a fine concertina, the lowest and highest notes of the syren, the shaking of an iron plate, as in the production of artificial thunder, the notes of a violin; but was affected to a certain extent by the notes emitted from a series of steel rods of different lengths, struck as the street boys strike the iron railings with a piece of wood.

The writer considers that the effect is simply that of "a resolution of forces," in which the motions of the flame are affected by the kindred vibrations of certain vocal sounds and noises, with which they unite, the result being no longer a thin perpendicular line, but a rude approach to a circular figure when perfectly harmonious or in unison, or other curious forms according to the nature of the combined movements of the flame and the air set in motion by the vocal organs, or by any noise, such as the rattling of keys. It would appear from the syren experiment that the vibrations which affect the flame must not occur too rapidly.

The shape of the flame produced by two jets of gas crossing each other, as in the fish-tail burner, is the resultant of two opposing currents of gas.

If one gas flame can affect another, and alter its form, it is easily conceived that any impulse of air, instead of burning gas, would give the same result as in the sensitive flames.

Any noise repeated a given number of times will have a proper musical value. A crack, a snap, a bounce, a crash, an explosion, a rumbling, may be classed together as noises; and yet it will be found that it is quite possible to demonstrate that some of these noises may be converted by constant repetition into true musical sounds.

Mr. Pichler made for the writer an enlarged syren, having six large holes, alternately opened and shut by a revolving plate with six apertures, provided with lean-to roofs, like those placed over the cabin stairs of steam or other vessels.

When this contrivance is connected with powerful bellows, the first noise heard is that of a rushing wind, alternately escaping and cut off; and as the velocity of the revolving plate is gradually raised, the noise is changed to a series of musical sounds, rising in the scale according to the force used to impel the air through the apparatus.

The ordinary syren, invented by Cagniard Latour, and so called because (like the sea-nymphs who charmed with their songs all who came near them) it is erroneously supposed to give sounds under water, consists of a lower plate, forming the top of a circular box, which is perforated with, say, ten slanting holes at

equal distances; above this plate another revolves, also perforated with a similar number of apertures, not bored perpendicular to the axis, but inclined in the opposite direction to those in the lower plate, so that when one aperture is over the other, a zigzag figure is the result. The upper plate carries a shaft or axis, which has an endless screw at the top; and as this revolves by the force of the wind escaping from the bellows, it transmits the motion to a wheel with one hundred teeth, and every time the latter goes round once the one hundred revolutions are recorded on another wheel; and as both are provided with

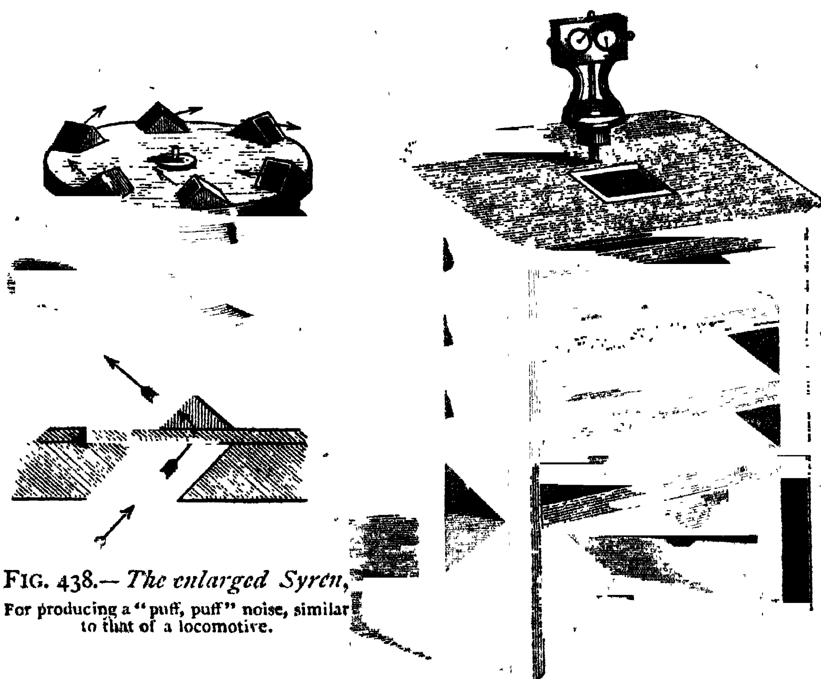


FIG. 438.—*The enlarged Syren,* For producing a "puff, puff" noise, similar to that of a locomotive.

FIG. 439.—*The Syren and Bellows.*

needles, which move over numbered dials, like those of a gas meter, the exact number of revolutions per second can be determined. The sound gradually rises as the velocity is increased, until the syren fairly screams, and emits such piercing cries that, had the ancient ladies called syrens performed in a similar manner, it is easy to understand why Ulysses stuffed his ears with wax and tied himself to the mast of his vessel to avoid the dangerous effects of their vocal powers, which might, like some of the modern street-singers, have driven him mad and overboard, to escape from the excruciating torment.

Supposing the syren to be urged with the bellows until the deepest note of the bass, viz., C_1, *do*, is obtained. If this be continued for two minutes, or 120 seconds, the dial would record 1,536 revolutions; but the revolving disc

has ten holes, then $1{,}536 \times 10 = 15{,}360$, which, divided by 120, gives 128 vibrations per second for the note C_1, or that which is called *do.* The syren is, therefore, extremely valuable, as it shows the number of impulses per second required to produce any given sound; and thus it is found by actual experiment that the seven notes of the gamut, commencing with the deepest note of the bass, are as follows:

C_1	Do	. . .	128 vibrations per second.
D_1	Re	. . .	144
E_1	Mi	. . .	160
F_1	Fa	. . .	170
G_1	Sol	. . .	192
A_1	La	. . .	214
B_1	Si	. . .	240

The notes of other and higher scales would start with an index C_2 or C_3, &c.; whilst those of a lower scale would be designated as -1, -2, -3, &c.

These figures have a constant relation to the length of the wave of sound to which they refer—a fact easily determined by the monochord already alluded to (p. 485, Fig. 435).

The last-named apparatus consists of a string or wire stretched by weights or a screw (as in an ordinary violin) across two bridges, one at each end; there is also a movable bridge, and, supposing this to be placed at a distance equal to a third of the whole length, and then vibrated by drawing a bow over it, the string divides itself into three parts, each of which has its own vibration or wave-like figure.

Between these parts there are points where the motion is almost *nil* or 0, called *nodal* or fixed points, whilst the part of the string vibrating between two fixed points is called the ventral segment.

This fact is proved by placing pieces of paper, cut like an inverted V, on the above-named parts, which remain as riders firmly seated at the nodal points, but are thrown off at the ventral segments.

The plates on which are produced, by vibration, the figures called Chladni's sand-figures (p. 474, Fig. 433) and membranes, present the same feature, and have points of rest (nodal points) where the sand collects to produce the figure, and other parts from which the sand is set into vibration and shaken off.

The musical scale or gamut—so called, it is said, because the inventor, Guido, of Arezzo, improved upon the ancient Grecian scale, and, in acknowledgment of its origin, called his scale from the Greek letter Gamma—the gamut consists of seven notes separated from each other by intervals, and, if repeated, again reproduced in periods of seven each, called a scale or gamut.

Each scale has waves of different lengths, that can be estimated by numbers. Taking the velocity of sound as equal to 1,024 ft. per second, if we imagine a string of that length vibrating once in that period of time, the length of the wave would be 1,024 ft.; if it made three vibrations in the same period, the length would be $1{,}024 \div 3 = 341{\cdot}333$.

It has been observed that the deepest bass note, C_1, is equal to 128 vibrations per second; therefore, $1{,}024 \div 128 = 8$ ft., *i.e.*, a note, C_1, is produced by 128 vibrations or waves, each of which is 8 ft. in length.

If a lower sound than C_1 is produced, viz., C_{-1}, or 16 vibrations per second, the length of each wave is 64 ft. When the sound is equal to 1,024 vibrations per second, or C_4, the length of each wave is 1 ft.

Having the two extremes, the lowest appreciable sound, consisting of 16 vibrations per second, C_{-1}, and the highest, C_4, or 1,024 per second, it is easy to work out a table of the length of the waves of the intermediate scales corresponding to the first note of the successive gamuts.

Savart considered that the lowest sound the human ear could appreciate consisted of from 14 to 16 vibrations, and the highest of 48,000 vibrations, per second.

Despretz, whose name is mentioned by Marloye as the physicist for whom he made the tuning-forks, considered that 32 vibrations and 73,700 per second represented the deepest and most acute sounds appreciable by the auditory nerve.

Dr. Wollaston stated that we are sensible of vibratory motion until it becomes a mere tremor, which may be felt and even almost counted.

A sound may be so shrill that, though audible to one person, it may not be heard by another.

Wollaston mentioned the case of a friend of his, whose power of hearing, though excellent, did not permit him to appreciate the chirping of the house-sparrow.

The same great philosopher remarks that

"The suddenness of transition from perfect hearing to total want of perception occasions a degree of surprise, which renders an experiment on this subject, with a series of small pipes, among several persons, rather amusing.

"A pipe, one-fourth of an inch in length, produced a sound supposed to be about six octaves above the middle F (which was the limit of his own hearing); but some persons could not hear that, and others could hear higher. The whole range of human hearing, between the lowest notes of the organ and the highest of insects audible to man, is supposed to be about nine octaves; and, although some individuals can hear sounds not audible to others, there is at least but little difference in the range of human hearing, although the existence of a limit cannot be disputed."

Before dismissing the syren, it is of importance to speak of a simple form of this instrument, first devised in Paris, and now made by Mr. Ladd.

A disc, perforated with holes in regular and irregular intervals, is turned round fast or slow, and whilst revolving a strong blast of air is blown through the holes by the mouth with a flexible tube and ivory mouthpiece and jet. It is very interesting to mark the rise of the notes produced as the velocity of the holes increases or decreases, discoverable by moving the jet from the circumference to the centre. The following description of the number and arrangement of the perforations is furnished with the instrument:

"The disc is perforated with 1,682 holes, apportioned into twenty-four concentric circles, the fifteen interior ones being divided into regular, and the remainder into irregular, intervals. The former are divided in the following proportions:—For every two holes in the first circle (counting from the centre) there are three in the second, four in the third, five in the fourth, six in the fifth, eight in the sixth, ten in the seventh, twelve in the eighth, sixteen in the ninth, twenty in the tenth, twenty-four in the eleventh, thirty-two in the twelfth, forty in the thirteenth, forty-eight in the fourteenth, and sixty-four in the fifteenth. If with a small tube you blow into these circles whilst the disc is in rapid rotation, a series of musical notes will be obtained, allied to each other in the relative proportion of the numbers. Looking at the outer portion of the disc, lines of holes are observed radiating from the centre, and dividing



FIG. 440.—*New Form of Syren, made by Ladd.*

the disc into twenty-four equal parts; and, if the other holes were stopped, each of these rings would produce a single sound the same as the sixth row of the inner series. This note will form the fundamental of all the harmonics. If we take a point in the first of the external rings, and, starting from it, with a pair of compasses repeat the distance between it and the first intermediate hole five times, it will correspond with four of the fundamental spaces; and if a single jet of air be forced through these holes whilst the disc is rotating, the idea conveyed to the mind will be precisely the same as if two separate notes were sounded together—the two notes being a fundamental and its third, the proportions of the vibrations being as 5 : 4. The second row is divided in the ratio of 4 : 3—this will give a fundamental and its fourth (or sub-dominant); the third row is divided as 3 : 2, giving the fundamental and its fifth (or dominant); the fourth row, divided as 5 : 3, gives a fundamental and its sixth; the fifth row is as 7 : 4—this giving a fundamental and flat seventh; the sixth row has a combination of four holes, in the proportion of 6 : 5 : 4 : 3—this will give a perfect chord of four notes; the seventh row has four holes, in the proportion of 8 : 6 : 5 : 4—this will give a perfect chord with octave of the fundamental; the eighth row is divided in the proportion of 5 : 4 : 3, giving a perfect major triad with inverted fifth; and the last row is divided in the proportion 6 : 5 : 4, which forms a perfect major triad."

The conversion of noise into musical sounds is shown in the most elegant manner by an instrument devised by Froment.

A small electro-magnet, with a break fastened at one end in the ordinary way to one pole and vibrating on the other pole, is connected with a small battery; directly contact is made, the break, acting like a tiny hammer, is attracted so frequently to the other pole, which it strikes, that a sound like that emitted by a bluebottle is distinctly audible, rising to an acute sound as

the screw is moved, which regulates the distance of the break and increases the number of contacts per second. Thus a hammering noise is converted by mere repetition into a musical sound.

Speaking of the bluebottle and of the supposed production of the sound by the vibrations of its wings, a friend of the author writes as follows:

"I have read of, and also tried, the cruel though interesting experiment of taking off the wings of flies, bluebottles, &c., and have noticed that sounds were emitted after the disappearance of the wings. How, then, can this be accounted for, if the sound (as stated in some books) be produced by the vibratory motion of the wings? And, moreover, we read in other books on 'Acoustics' of a peculiar mechanism, particularly in bluebottles and humble-bees, through which the rapid transmission of air causes a fibrous thread-like apparatus to vibrate, thus causing the peculiar buzzing sound made by those insects."

On the principle already explained, it is easy to understand why sounds are obtained by burning a jet of hydrogen inside a glass tube. This curious fact was first observed by Dr. Higgins in the year 1777, and further examined by Brugnatelli, Pictet, De la Rive, and Faraday.

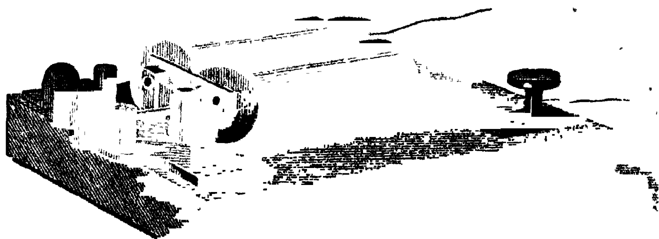


FIG. 441.—*Froment's Apparatus.*

The latter philosopher considered that the sounds were producible by the gas not burning silently, but with a series of inaudible explosions in the open air, rendered audible when burnt in a tube by the *resonance* of the tube, a term that will be more fully explained hereafter.

It is not every glass tube that will resound or sympathize with the explosions of the gas; but, generally speaking, it is easy to obtain them, and, as Mr. Barrett remarked in his lecture given before the Dublin Royal Society, "thus rough and rude taps and hard and harsh explosions can be chased into perfect melody by mere rapidity of succession.

"The condition of the flame when burning within the tube is shown by a moving mirror. It was seen that when the flame was silent and the mirror moving, a band of light was produced; but when the flame was sounding, this luminous ribbon was broken up into a series of disjointed images of flame. The effect of lengthening the tube in which the flame was burning was next shown, and a series of gas jets burning within glass tubes of varying length gave a corresponding series of musical notes of varying pitch. By placing the finger upon the top of these tubes, the sound could be quenched, and thus a novel musical instrument could be constructed. From glass tubes

the lecturer passed on to show the effects of flames burning within extremely long tin tubes. Within a tube 6 ft. long and about $1\frac{1}{2}$ in. in diameter, the flame of a large gas-burner gave a loud, unmusical roar. By adding to the end of this tube a glass chimney, it was seen that when the flame was sounding it was broken up into wild confusion. By enclosing a still larger gas-flame from a huge Bunsen's burner within a tube 18 ft. long and 3 in. in diameter, a deep roar was obtained, intermingled with loud reports similar to the discharge of musketry.

"Returning once more to the gentler music of the small glass tubes, two flames, enclosed in their respective tubes, were taken and made to emit notes of the same pitch. This point was gained by shifting to and fro a paper slider, which moved stiffly at the upper extremity of one of the tubes. When the notes were nearly in unison a series of intermittent sounds or *beats* were obtained, due, as is well known, to the mutual extinction at certain intervals of the two sounds. Corresponding beats were obtained from two organ-pipes and two tuning-forks nearly in unison. One of these tuning-forks, mounted on its resonance case, being silent, the other, unmounted, was now struck, and its prongs brought near to, but not touching, those of the first fork: at first no sound could be heard, but by degrees the unmounted fork transferred its motion to the mounted one, and the sound of the latter slowly welled forth. The sound of the voice can thus be transferred to the strings of a pianoforte, and in the same way a flame can be made to accept and resound to a note of the proper pitch. This was illustrated as follows:—A singing flame, by adjusting the paper slider, was tuned to the note of a certain fork; the tube was then raised slightly, so that the sound could be quenched by momentarily placing the finger on the top of the tube. On now striking the fork, and

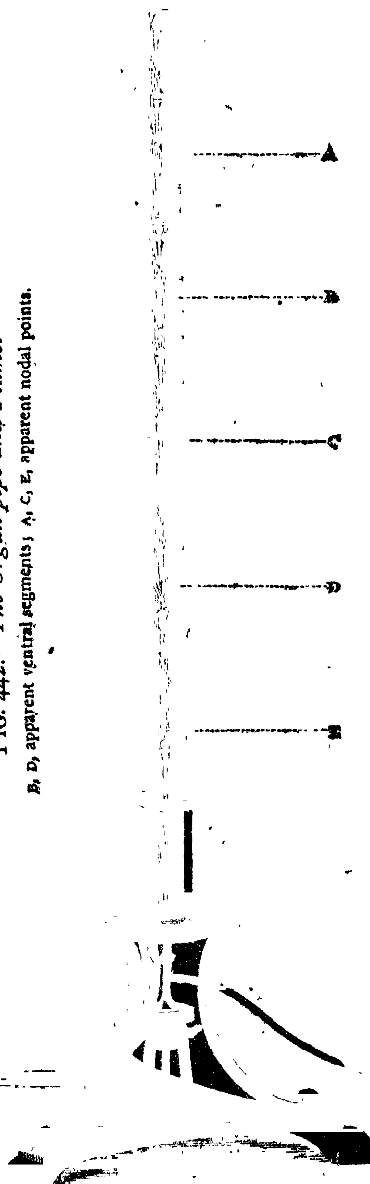


FIG. 442.—*The Organ-pipe and Flame.*
B, D, apparent ventral segments; A, C, E, apparent nodal points.

holding it over a resonant jar, the flame instantly started into song. The same effect was shown by the syren, and also by the human voice. Retreating to some distance from the flame, the latter could be made to respond at pleasure by pitching the voice to the proper note, whilst it remained utterly unaffected by any note not in unison with itself. Musicians would find such a flame a faithful monitor in training the voices of their pupils."

The apparatus used by the writer at the Polytechnic is shown on the preceding page. (Fig. 442.)

The organ-pipe was 15 ft. in length, and emitted a fine deep sound when an Argand burner was used, whilst with a large Bunsen's burner the sound rose with the increased supply of gas to a roaring noise, which reminded one of the vocal powers of the lion at the Zoological Gardens, just before the tantalizing (to him) bits of raw meat are served for his dinner.

The beats were very distinct; and on one occasion the writer noticed that, whilst the pipe was sounding, the heated air appeared to divide itself into ventral segments and nodal points, the latter being apparently discoverable by the increased heat where the hot air remained at rest, as at the nodal points, whilst the cooler parts of the pipe might be the ventral segments, where agitation mixed the air, and prevented that quiescence which would give time to the air to give out its heat to the sides of the pipe; but, curious to say, this result could not be obtained again, and, therefore, the absolute proof that a column of heated air can divide itself into waves emitting a greater heat at the nodal points than the ventral segments remains yet to be obtained.

Mr. Becker, of Elliott's, who constructed the organ-pipe apparatus, also arranged for the writer a series of brass tubes increasing in length, having inside them small Bunsen burners, and producing, when the valves fixed to the top of each tube were lifted by strings attached to a key-board, the notes of the gamut. (Fig. 443.)

With this gas-flame organ Herr Shalckenbach, the much-respected organist of the Polytechnic, could play simple tunes, to the great admiration and delight of the youthful spectators.

It has already been remarked that the gas-flames do not give out or produce sound, except they are clothed or surrounded with a tube made of glass, metal, or any other convenient substance. The curious jumping up and down of a single flame that precedes the evolution of sound has been ascribed (as already stated) by Faraday to a series of explosions. The writer is inclined to doubt this being the correct explanation, because whenever a true explosion takes place, the flame is extinguished. It has more to do with the current which is constantly dragging the flame upwards, and the fire is as constantly running downwards to the jet: here are a series of impulses, an up-and-down motion, or vibratory power, sufficient to set the air into waves, which are communicated by contact to the glass tube, and this, by resonance, produces the sound.

If an Argand burner be used, the flame is quite different: whilst the sound is being produced, the flame overflows the outside of the ring, and, burning very blue, shows the rapidity of the current of air. It seems to be beaten downwards, as if one current of air passed up the centre of the Argand tube, and another came down outside; but there is not any indication of an explosion, except when the interior of the tube is corked or stopped, and then the flame is continually extinguished by explosions.

When tested by the mirror, the streak or band of light is continuous: there are no breaks as with the single flame because that is prevented by the com-

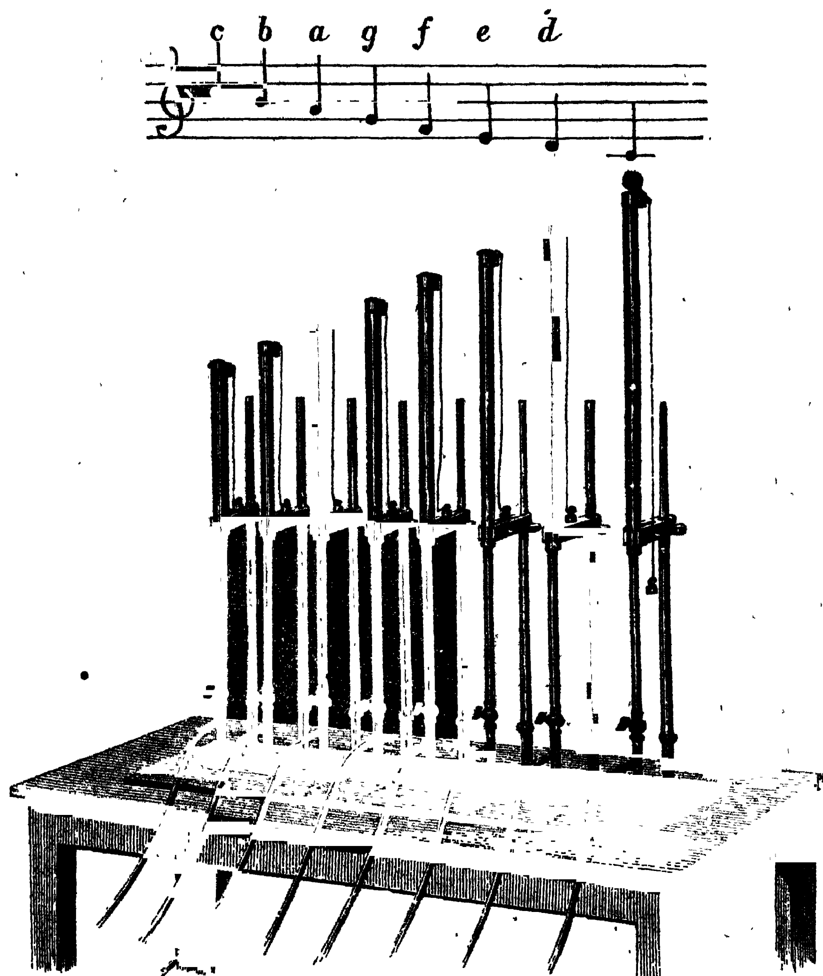


FIG. 443.—*The Gas-flame Organ.*

plete combustion of the gas; there is no jumping up and down and intermittent combustion,—it is continuous; and yet sound is evoked. The ring of burning gas is violently agitated by the current of air in the tube; it is constantly wishing to rise, and is as constantly beaten down; thus it is the current of air that determines the whole effect, and there are no explosions whatever. If one really occurs, the flame is blown out, as might be expected. It is probably intermittent combustion which sets the air vibrating.

To show how completely the sound is affected by the rate or rapidity of the

current of air, the writer used a single jet and flame, so arranged that it could be bent down to any angle to the perpendicular with the tube surrounding it. The flame emitted sound at an angle of 60°, but every degree after it decreased, until at 50° it stopped and refused to vibrate; and when the tube was horizonal, the flame, as might be expected, stopped singing altogether, and clung to the upper part of the tube. The reader will, no doubt, be interested with extracts from Faraday's own paper,

"ON THE SOUNDS PRODUCED BY FLAME IN TUBES, &c.,
"By M. FARADAY, Chemical Assistant in the Royal Institution.
"May 11, 1818.*

"There is an experiment usually made in illustration of the properties of hydrogen gas, which was first described by Dr. Higgins in 1777, and in which the tones are produced by burning a jet of hydrogen within a glass jar or tube. These tones vary with the diameter, the thickness, the length, and the substance of the tube or jar, and also with the changes of the jet. After Dr. Higgins, Brugnatelli, in Italy, and Mr. Pictet, at Geneva, described the experiment, and the effects produced by varying the position of the jet and tube; and M. de la Rive read a paper at Geneva in which he accounted for the phenomena by the alternate expansion and contraction of the aqueous vapour. That they are not owing to aqueous vapour, from some experiments to be described, I have no doubt: they are caused by vibrations similar to those described by M. de la Rive, but the vibrations are produced in a different manner, and may result from the action of any flame. I was induced to make a few experiments on this subject. That the sounds were not owing to any action of aqueous vapour was shown by heating the whole tube above 212°, and still more evidently by an experiment in which I succeeded in producing them from a jet of colza oil gas. That they do not originate by vibration of the tube, caused by the current of air passing through it, was shown by using cracked glass tubes—tubes wrapped in cloth; and I have obtained very fine sounds by using a tube formed at the moment by rolling up half a sheet of cartridge paper, and keeping it in form by grasping it in the hand.

"Sir H. Davy has explained the nature of flame perfectly, and has shown that it is always a combination of the elements of explosive atmospheres. In continued flame, as of a jet of gas, the combination takes place successively and without noise as the explosive mixture is made. In what is properly called an explosion, the combination takes place at once throughout a considerable quantity of mixture, and sound results from the mechanical forces thus suddenly brought into action, and a roaring flame presents something of the appearance of both. Now, this I believe to be exactly analogous to that which takes place in what have been called the singing tubes, but in them the explosions are generally more minute and more rapid. By placing the flame in the tube, a strong current of air is determined up it, which envelopes the flame on every side. The current is stronger in the axis of the tube than in any other part, in consequence of the friction at the sides and the position of the flame in the middle and just at the entrance of the tube. An additional effect of the same kind is produced by the edge obstructing the air which passes near it. The air is, therefore, propelled on to the flame, and, mingling

* "Quarterly Journal of Science," Vol. V.

with the inflammable matter existing there, forms portions of exploding mixtures, which are fired by the contiguous burning parts, and produce sound in the manner already described with a roaring flame, only the impelled current being more uniform, and the detonations taking place more regularly and in smaller quantities, the sound becomes continuous and musical, and is rendered still more so by the effect of the tube in forming an echo.

"That the roaring flame gives sound in consequence of explosions can hardly be doubted.

"An experiment may be made with coal-gas. Light a small Argand burner with a low flame, and bring a glass tube, which is very little larger than the diameter of the flame, down upon it so as nearly to include it. The current of air will be impelled upon the external part of the flame, it will remove the limit of combustion a little way up from the burner, that part of the flame will vibrate rapidly, burning with continued explosions, and an irregular tone will be obtained. Remove the burner, and attach a long slender pipe to the gas-tube, so as to afford a candle-flame that may be introduced into the tube. Light it and introduce it about five or six inches. and a clear musical tone will be obtained."

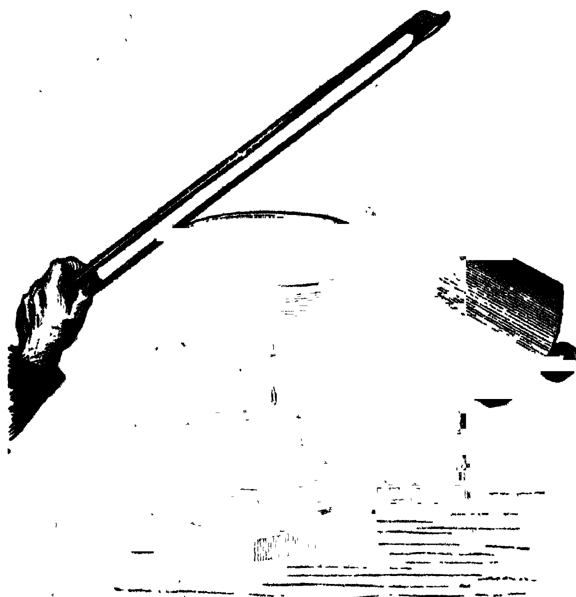


FIG. 444.—*Savart's Apparatus for showing Resonance.*

Resonance is defined by Brande as the returning of sound by the air acting on the bodies of stringed musical instruments. M. Savart's apparatus (Fig. 444) is, perhaps, the most perfect contrivance for showing how sound may be strengthened. We know, in ordinary musical instruments, such as the violin and violoncello, that the mere vibration of the strings, unless strengthened by

the hollow body, would give but a feeble sound. So with Savart's arrangement, a hemispherical bell is sounded by drawing a violin bow across the edge.

The quantity of sound produced is very moderate, and the bell does not ·e a loud sound; but directly the mouth of the cylindrical box, made of ..., the precise length and breadth of which has been carefully ... ought round and facing the vibrating metal, the sound is instantly and enormously increased, because the air set in motion by the bell communicates its vibrations to the cylindrical box, a greater surface is thrown into the same trembling condition as the bell, and, as the two sympathise and are in unison with each other, the combined tremblings of the bell and reverberations of the box mutually assist and exalt each other. Whilst a loud sound is being obtained, it is very curious and striking to notice the difference of effect when the mouth of the cylinder is turned away from the bell.

445.—*Tuning-fork vibrating over the mouth of a Bottle.*

It is not every cylinder of any depth or breadth that will answer the purpose. This is shown by another experiment with a tuning-fork and bottle: the former, when struck and vibrating, must be applied to the ear to be heard; but, if held over the little bottle, the sound is loud enough to be heard in a large room, and yet it entirely fails when another and larger bottle is used.

When a tuning-fork is mounted on a box, the sound is strengthened and is much louder, in consequence of the resonance of the hollow box.

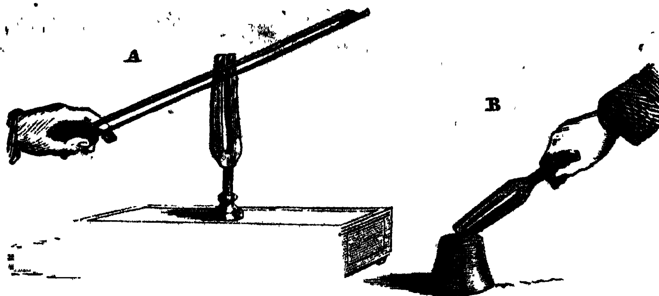


FIG. 446.

A, Tuning-fork fixed on a box, sounded by drawing a violin-bow across it; B, ditto, sounded in the ordinary manner.

A tuning-fork is used for musical purposes because it always gives the same note of the same pitch. It has been a great source of annoyance to singers that the ... itch has been getting higher, and that it has damaged and will continue to harm the delicate vocal organs of good singers, who, emulating each other's example, try to outvie one another. The concert pitch is different in London, Paris, Vienna, and Milan. Meetings of musical and scientific ... held in this country to try to alter this state of things, and now

reform appears to be certain, because our greatest tenor has refused to sing in any other pitch than that of the normal tuning-fork of Paris, which gives 870 vibrations per second, *i.e.*, la_3, or the sound produced by the third open string of the violin.

Mr. Hentry Walter Bates, in his deeply interesting work entitled, "The Naturalist on the River Amazon," gives a remarkable illustration of resonance in connection with an insect of the cricket tribe, "which is found in this neighbourhood, the males of which produce a very loud and not unmusical sound by rubbing together the overlapping edges of their wing-cases. The notes," he says, "are certainly the loudest and most extraordinary that I ever heard produced by an orthopterous insect. The natives call it the 'tananá,' in allusion to its music, which is a sharp resonant sound resembling the syllables *ta-na-ná*, *ta-na-ná*, succeeding each other with little intermission. It seems to be rare in the neighbourhood. When the natives capture one, they keep it in a wickerwork cage, for the purpose of hearing it sing. A friend of mine kept one for six days. It was lively only for one or two days, and then its loud note could be heard from one end of the village to the other. When it died, he gave me the specimen, the only one I was able to procure.

"It is a member of the family *Locustidæ*, a group intermediate between the crickets *(Achelidæ)* and the grasshoppers *(Acridiidæ)*. The total length of the body is two inches and a quarter when the wings are closed, has an inflated, vesicular, bladder-like shape, owing to the great convexity of the thin but firm parchmenty wing-cases, and the colour is wholly pale green. The instrument by which the tananá produces its music is curiously contrived out of the ordinary nervures of the wing-cases. In each wing-case the inner edge, near its origin, has a horny expansion or lobe upon one wing; this lobe has sharp raised margins on the other, and the strong nervure which traverses the lobe on the under side is crossed by a number of fine sharp furrows like those of a file. When the insect moves rapidly its wings, the file of the one lobe is scraped sharply across the horny margin of the other, thus producing the sounds, the parchmenty wing-cases and the hollow drum-like space which they inclose assisting to give resonance to the tones. The projecting portions of both wing-cases are traversed by a similar strong nervure; but this is scored like a file only in one of them, in the other remaining perfectly smooth. Other species of the family to which the tananá belongs have similar stridulated organs, but in none are these so highly developed as in this insect. They exist always in the males only, the other sex having the edges of the wing-cases quite straight and simple. The mode of producing the sounds and their object have been investigated by several authors with regard to certain European species. They are the call-notes of the males.

"In the common field-cricket of Europe the male has been observed to place itself, in the evening, at the entrance of its burrow, and stridulate until a female approaches, when the louder notes are succeeded by a more subdued tone, whilst the successful musician caresses with his antennæ the mate he has won. Any one who will take the trouble may observe a similar proceeding in the common house-cricket. The nature and object of this insect music are more uniform than the structure and situation of the instrument by which it is produced: this differs in each of the allied families above mentioned. In the crickets the wing-cases are more symmetrical; both have straight edges and sharply scored nervures, adapted to produce the stridulation. A distinct portion of the edges is not, therefore, set apart for the elaboration of a sound-

producing instrument. In this family, the wing-cases lie flat on the back of the insect, and overlap each other for a considerable portion of their extent. In the *Locustidæ* the same members have a sloping position on each side of the body, and do not overlap, except to a small extent near their bases. It is out of this small portion that the stridulating organ is contrived. Greater resonance is given in most species by a thin transparent plate, covered by a membrane, in the centre of the overlapping lobes.

"In the grasshoppers *(Acridiidæ)* the wing-cases meet in a straight suture, and the friction of parts of their edges is no longer possible. But Nature furnishes the same fertility of resource here as elsewhere, and, in contriving other methods of supplying the males with an instrument for the production of call-notes, indicates the great importance which she attaches to this function. The music in the males of the *Acridiidæ* is produced by the scraping of the long hind-thighs against the horny nervures of the outer edges of the wing-cases, a drum-shaped organ, placed in a cavity near the insertion of the thighs, being adapted to give resonance to the tones."

VIBRATIONS OF STRINGS, RODS, PLATES, AND COLUMNS OF AIR.

The tuned string, according to one of our best dictionaries, means "the chord of a musical instrument, as of a harpsichord, harp, or violin." The definition is to a certain extent philosophical, as the amount of vibration or undulation communicated by a string alone to the air would be too small to be audible. It is, therefore, necessary to connect the string with a sounding-board; and thus the sound of violins or pianos is found to depend mainly on that part of the instrument; hence the great care bestowed on the construction of the sounding-board.

There are two sets of vibrations which can be set up in strings:

I. Longitudinal, or those which are produced in the direction of the length.
II. Transversal, or those which are perpendicular to the string.

In the explanation of the monochord (p. 485), we have already spoken of those vibrations which belong to the latter class, and are of so much importance in music. Four laws rule these vibrations:

I. The stretching power being always the same, or tension constant, the number of vibrations per second, or any other period of time, is inversely proportional to the length.
II. The number of vibrations are in the inverse ratio of the squares of the diameter of the string.
III. The rate of vibration is directly as the square root of the stretching weight.
IV. The number of vibrations of the string is inversely proportional to the square root of its density.

In a series of experiments, where strings made of various substances, such as catgut, steel or copper wire, string, &c., are used, the number of vibrations is inversely proportional to the square root of the *weight* of the string.

The division of the string into ventral segments—the parts where the greatest movement occurs—and nodal points, or points of rest, has already been mentioned in connection with the monochord, and has been further

elucidated in the article on the Undulatory Theory of Light (pp. 6 and 7, Figs. 4 and 5).

"It follows," says Marloye, "that as the transverse vibrations of strings are in the inverse ratio of their diameters and in the inverse ratio of their lengths, knowing the number of vibrations made by a given string, this string can serve to determine the number of vibrations of any sound whatever, if it be stretched on a suitable instrument, since we can thence easily deduce the number of vibrations which any portion of this string ought to perform.



FIG. 447.—*Differential Sonometer, usually provided with an assortment of Weights.*

"This apparatus is provided with three divided rules. The first gives the modified chromatic gamut; the second gives the true chromatic gamut, and also the harmonic divisions of the string; and the third is a French *mètre* (about 3 ft. 3 in.), divided into $\frac{1}{1000}$ parts of its length from end to end. With this apparatus and Marloye's tuning-fork, we can take the number of vibrations of any sound whatever in less than a minute, by referring to the table which accompanies the apparatus.)

"To verify the law of tensions with this instrument, we stretch a string with the sum of the weights; then, by means of tuning-pegs attached to the instrument, we stretch a second string, which we bring into unison with the first; we then reduce by three-fourths the weight attached to the first string, and we compare its sound with that of the string which is fixed.

"For the verification of the law of diameters, we compare alternately the sound of strings whose diameter is known with that of the fixed string, which we bring into unison with one of them. We proceed again in the same way for the law of densities; but for that of lengths, as for other experiments, we only make use of the fixed string, to which we then give the degree of tension adapted to make it sound as well as possible.

LONGITUDINAL VIBRATIONS OF STRINGS.

"In strings of the same substance, which vibrate longitudinally, the numbers of vibrations are in the inverse ratios of their lengths, whatever may be their diameter and tension. Nevertheless, in taking the half of the string with the bridge, we have always less than the octave of the entire string; and that evidently is owing to the string vibrating between two immovable points, although shorter by half, since the harmonic sounds the octave.

"Marloye's apparatus for demonstrating the laws of longitudinal vibrations for strings of metal, and other experiments, is made of mahogany, and is a

companion to the differential sonometer. Its extremities are furnished with handsome bronze vices, acting as fixed bridges, and made to oppose the transmission of vibrations beyond the extremities of the string; thus the strings stretched on this apparatus vibrate with such facility that we obtain from them a very pure sound by rubbing them gently near their extremity with the end of a bow. As in the differential sonometer, a *mètre*, divided into $\frac{1}{1000}$ parts, separates the two bridges, and the strings are stretched as we please, either by weights or by pegs. A movable pair of leaden pincers and a divided rule permit us to make the gamut either longitudinal or transversal.

Longitudinal Vibrations of Rods.

"In rods of the same material the numbers of vibrations are in the inverse ratio of the lengths, whatever be their form and diameter.

"For this demonstration four steel rods are used, viz., two cylinders of a *mètre* in length and of different diameters, one flat, of the same length, and one cylindrical, shorter by one-half; also four deal rods.

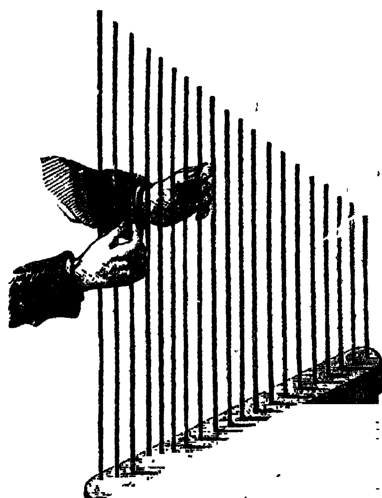


Fig. 448.
Marloye's Musical Instrument founded on Longitudinal Vibrations.

"Although the law just expressed is considered as a general law, it appears notwithstanding to have its limits, like many other laws of acoustics. I thought it would appear curious," says Marloye, "to show at acoustic lectures that a hollow tube sounds as if it were full; for that purpose I had brass tubes and rods of the same diameter drawn, and I then saw, contrary to my expectation, that the rapidity of sound is always greater in a tube than in a rod when the alloy is sensibly the same; thus, for example, for a *mètre* in length the tube sounds about half a note higher than the rod. Still, if the thickness of the sides of the tube be the third of its interior diameter, it sounds pretty nearly as if it were full.

"The foot of this instrument is composed of a stand, on which is raised a plank of deal, 2 ft. 7½ in. high, 1 ft. 7½ in. broad, and 2¾ in. thick. On this foot are implanted twenty deal rods, the longest of which is about 5 ft. 3 in. Commencing from this, the succession of white rods forms the diatonic gamut, and the half-notes, which complete this gamut and render it chromatic, are represented by red rods.

"This instrument, which is played on by rubbing the sticks with the fingers, which we previously dip into powdered rosin, yields very sweet tones, that can

be swelled or diminished at pleasure, and give this instrument much expression in the hands of any person who can play well on it."

Vibrating Plates.

In plates of a similar kind, the numbers of vibrations are in the inverse ratio of their homologous dimensions; and in plates of the same shape, the numbers of vibrations are in the direct ratio of their thickness, and in the inverse ratio of their surfaces.

The apparatus for demonstrating the laws of vibrations of vibrating plates (Fig. 433, p. 474) is composed of a table surmounted by six plates of brass, three round and three square. In the three plates of the same form, two are alike, two whose thicknesses are as 1 : 2, and two whose surfaces are as 1 : 4.

It has already been explained (p. 503, Fig. 444), in the experiment with Savart's bell apparatus with resounding tube, that if we cause a bell, a plate, or any other substance which has a certain extent of surface to sound, and present to a ventral segment of its vibrations the orifice of a tube open at both ends or closed at one end, this tube sounds with energy if, by its dimensions, it be in unison with the vibrating substance.

These circular plates are all fitted for experiments on the rotation of lycopodium.

When the elasticity varies in a circular plate so as to give different axes, if we act on this plate with a bow at the extremity of two of these axes, or between two axes, the fundamental note that it will yield will differ for each case, as also the figure which the sand will assume,

Marloye constructed an apparatus for demonstrating that the rotation of lycopodium on circular plates is only owing to the translation of the nodal lines round the circle.

To make the experiment in question, we bring the two tubes to the length corresponding to the note we wish to make sound; we strew the plate with lycopodium, we make it vibrate, and when the sound is well sustained, and the lycopodium turns rapidly, we bring the tube over the plate. Then each belly, or ventral segment, of vibration which passes under the tube makes it sound, which causes intermissions in the note, which at first are very rapid, but subsequently become slow if we cease to act on the plate with the bow; nevertheless, it often happens that, long after the lycopodium is at rest, we still hear waves passing. With respect to the

Transverse Vibrations of Blades and Rods,

in simple transverse vibrations, the numbers of vibrations are in the inverse ratio of the square of their lengths, and in the direct ratio of their thicknesses, no matter what be their breadth.

As an illustration of such vibrations, there is an instrument used by savages, called "*claque-bois.*" This contrivance, which the savages make of hard wood, and which they strike with a stick of hard wood, Marloye makes of deal; and it is struck by a piece of wood covered with leather, to make it more perceptible that, independently of the noise occasioned by the shock, the wood is susceptible of yielding very pure and even very agreeable notes. This instrument is composed of eight deal blades, forming a diatonic octave, and mounted so as to be played on with ease.

A piano constructed of paving-stones is one of the novelties recently reported from Paris. The Abbé Moigno gave a lecture on sound, and exhibited, amongst

other instruments, a piano, the keys of which were large pebbles of various shapes and sizes, supported freely on short tapes, attached to horizontal and parallel bars of wood. The pebbles had, with almost incredible labour, been selected to form two full octaves of the upper scale, and no doubt thousands had to be picked up and tested before the right ones were found. Several airs were played on this singular instrument with, it is said, wonderful accuracy and effect.

Longitudinal Vibrations of Columns of Air.

M. Marloye, of Paris, who has made some of the finest acoustic apparatus, a great deal of which the writer possesses, says, "Let us recall to mind, in the first place, that when we gradually increase the rapidity of a current of air which causes a tube long in proportion to its diameter to vibrate, we make it yield, as in the French horn, a series of harmonic sounds, passing rapidly from one to the other, and the relations of whose vibrations are to each other as the natural arrangement of numbers, 1, 2, 3, 4, &c., when the tubes are open at both ends; or in the order of the odd numbers, 1, 3, 5, 7, &c., when they are closed at one end.*

"To show this, two long glass tubes, one open and the other closed, fitting to a copper stop-tap to regulate the current of air, are used.

"When a column of air vibrates longitudinally, the nodes of vibration are always at the ventral points and reciprocally, and we may close the tubes at the nodes or open it at the bellies without the sound undergoing any change.†

"When a cylindrical column of air is put in vibration by an intermitting current of air, as with a French horn or clarionet mouthpiece, in the first place, if the tube be turned so as to form a helix, the tone is sensibly the same as if it were straight, only the sound is less loud, and is produced with less facility, according as the radii of the curves are shorter; secondly, it sounds with more facility, and yields sounds of much greater intensity, when it is terminated in an expanded form, like a trumpet, which, however, has but little influence on its tone; thirdly, the sounds it yields are grating according as its diameter is more narrow, no matter what be the nature of the sides of the tube and of the trumpet-shaped extremity.

"These facts are demonstrated by three tubes of the same length, viz., two of gutta-percha of different diameters, and one of vulcanized india-rubber, that we may roll into a spiral form when we please; and, besides, two trumpet-shaped ends, one of them of copper, and the other of gutta-percha.

"When we roll the caoutchouc tube into a spiral on a table, we observe it to unroll itself during the time it sounds."

The practical application of our knowledge of the condition of vibrating

* "It is a remarkable fact that the key-notes of two tubes of the same size, one open and the other closed at one end, when the tubes are long and narrow, yield sounds which differ from each other by an octave, the closed tube yielding the lower note This can easily be exemplified on the German flute by taking off the two lower joints, closing the holes of the remaining portion, and blowing into it when the end of the tube is closed and when it is open. The closing of the tube will be found to lower the sound by nearly an octave"

† "Thus, for the octave of the fundamental note a belly is formed at the centre of the tube; that is to say, the air at that part of the tube is neither rarefied nor condensed. Hence we may open the tube there without altering the note. We might also take off its upper half without changing the sound. When the tube yields a twelfth, or vibrates so as to form bellies at each third of its length, we may open the tube at the ventral points, or take off one-third or even two-thirds of its length, without altering the sound."—*From Pouillet's "Elémens de Physique."*

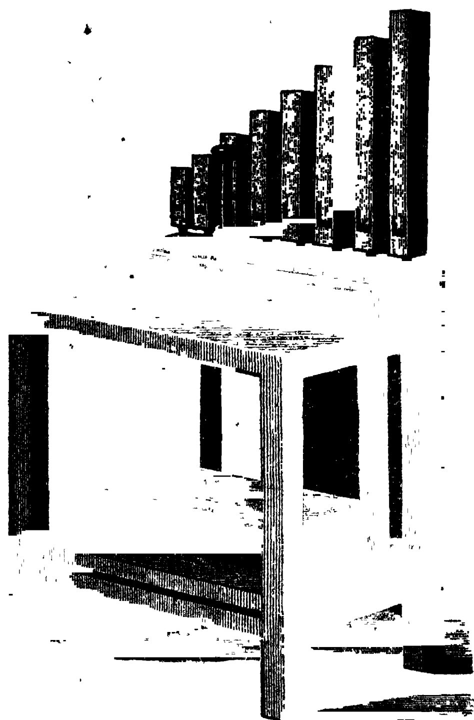


FIG. 449.—*Set of Experimental Organ-pipes fitted on Table, and Bellows.*

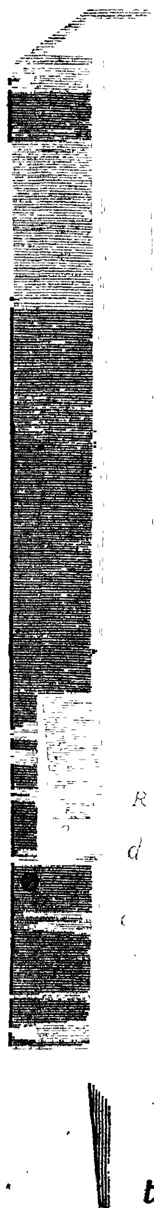


FIG. 450.

columns of air is well shown in the construction of organ-pipes, of which the drawing (Fig. 449) from Helmholtz's work is thus described by Tyndall:

"There are various ways of agitating the air at the ends of the tubes and pipes, so as to throw the columns within them into vibration. In organ-pipes this is done by blowing a thin sheet of air against a sharp edge. This produces a flutter, some particular pulse of which is then converted into a musical sound by the resonance of the associated column of air. You will have no difficulty in understanding the construction of this open organ-pipe (Fig. 450), one side of which has been removed, so that you may see its inner parts. Through the tube *t* the air passes from the wind-chest into the chamber *c*, which is closed at the top, save a narrow slit, *d e*, through which the compressed air of the chamber issues. This thin air-current breaks against the sharp edge, *a b*, and there produces a fluttering noise,

the proper pulse of which is converted by the resonance of the pipe into a musical sound. The open space between the edge, *a b*, and the slit below it, is called the *embouchure*."

The nodal points and ventral segments in the air of an organ-pipe are well shown with an apparatus constructed for the writer by Mr. Pichler, of Great Portland Street.

An organ-pipe giving a certain note is fixed on the top of the table connected with the bellows. By opening or shutting a valve, the organ-pipe sounds or is silent at pleasure.

The pipe is perforated in five places, into which tubes are inserted; opposite these are five gas-jets.

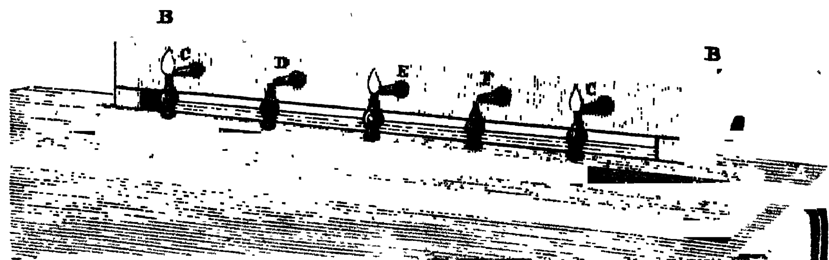


FIG. 451.—*Pichler's Apparatus for showing the Nodal Points in Organ-tubes.*

When the bellows is filled with air, and the organ-pipe, B, B, sounded, two of the gas-jets, D and F, are blown out with the violence of the movements of the air that belong to the ventral segments, and three, C, E, G, remain lighted, because they represent the places of rest, or nodal points. In the successful performance of this experiment it is, of course, necessary to have very minute jets of burning gas.

Marloye, always so clear and comprehensive, thus speaks of

EMBOUCHURES.

"In the embouchure *en flute* (as in the organ and flageolet) the vibrations are produced perpendicularly to the plane of the upper lip of the aperture, by the plate of air, which becomes an aërial reed when it meets with the slope of that lip. From thence results, as my apparatus demonstrates, that the note given is high in proportion as the aperture is lower and the curr rent of air more rapid.

"In the mouthpieces of wind instruments, such as the French horn, the trumpet, the ophicleide, &c., the artist's lips act as double reeds. The vibrations to which they give rise are longitudinal, and the sound produced becomes higher according as the cavity of the mouthpiece presses the lips into a more narrow space.

"The mouthpiece of the clarionet, as everybody is aware, is formed with a single reed, whereas the reed is double in the hautboy and the bassoon; but in both cases the reeds vibrate perpendicularly to the column of air, and the acuteness of the note which results increases with the rapidity of the current of air and the pressure of the lips."

An harmonium reed is a vibrating tongue of metal, and by enclosing this in a tube with glass sides the mechanism of the source of the musical note is distinctly seen.

Professor Willis has shown that vowel sounds may be produced either by partially closing a conical cavity excited by a reed placed at its apex, or in

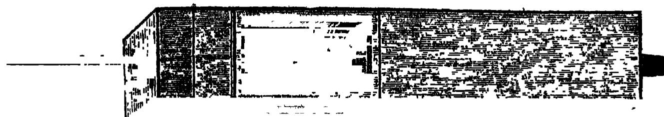


FIG. 452.—*A Reed.*

a column of air in a tube excited by a reed at its closed end, the particular vowel sound depending on the length of the tube.

Hence with all the so-called talking heads from the time of Albertus Magnus, who constructed the brazen head, which, it was said, had the power of talking, and is delineated at the commencement of this chapter (p. 473, Fig. 432), to the present period, when the Anthropoglossos flashed upon the giddy world of London a simulated imitation of the human voice, it is simply impossible to include in the space of the models of the human cranium or throat the necessary apparatus to pronounce the words such as Faber's genuine machine spoke, and which, of course, being an honest piece of scientific apparatus, utterly and entirely failed to excite public attention or to win the *golden* opinions of the multitude at the Egyptian Hall, where it was exhibited. The writer wishes sincerely he could find the *whereabouts* of Herr Faber. He can only hope he is not dead, but still lives, and will give to the world (to him ungrateful) those important acoustic and mechanical discoveries which enabled him to imitate so closely the vocal organs of man.

THE REFLECTION, REFRACTION, POLARIZATION, INTERFERENCE, AND HARMONY AND DISCORD OF SOUNDS.

A most enlightened and honest reviewer in the "Edinburgh Review," thus speaks of those properties which any student of waves of light, sound, or water would agree must prevail in all:

"If the vibrations of the air really produce sound as those of ether cause light, sounds ought to show all the well-known peculiarities of wave motion—reflection, refraction, interference, and polarization. The familiar phenomena of echoes prove that sound is reflected, but not that the reflected waves obey the same law as the waves of light. The simplest experiment to show this is, perhaps, the following:—Arrange two parabolic mirrors of burnished metal so that their axes coincide, and their cavities look at each other at the two points. At the axes known as the foci place a ticking watch and the ear. The observer hears the watch at a distance at which it is quite impossible to hear it without the mirrors. A little nearer the watch, or a little further from it than this point, there is absolute silence. A single point has thus been selected out of space

for a complicated effect of reflection. Let us now replace the watch by a bright point of light, and the ear by a sheet of note-paper. The image of the point comes out brilliant and well defined at the very spot where the ear heard the watch. The law of reflection for the two cases is, therefore, identical.

"In the same practical manner, but with different apparatus, the refraction of sound is proved; and not only this, but the index of refraction of sound, obtained from various solid, fluid, or gaseous substances, may also be determined." (See article on Light).

The same writer says, "The analogy between light and sound is not complete till we compare them with respect to another characteristic of wave motion—polarization. If we have an indefinite stretched horizontal string, plucked aside horizontally at one of its points and then let loose, the point will continue to move in a horizontal plane, and its oscillating movement will be transmitted along the string at a certain rate. As each successive point takes up the motion, it oscillates in the same horizontal plane through the string, and in no other. The rapidity of propagation will be definite. If the weight stretching the string be considerable for the length, we may have a musical note. This is an exact picture of a ray of polarized light." (The reader should refer back to the Polarization of Light.)

"Joseph Sauveur was born in 1653. For the first seven years of his life he was dumb, and he never could speak freely. He was also deaf, he had a false voice, and no appreciation of music. In order to verify his experiments, he was compelled to rely on the friendly help of musicians accustomed to estimate chords and intervals. His contemporary, the blind Professor Saunderson, taught optics in the University of Cambridge a few years later, but he has won for himself no abiding-place, except among the curiosities of science. In all the discussions of the ancients, and up to his time, certain relations of the notes themselves (octaves, fifths, &c.) had been constantly investigated. All the notes struck at one time could be compared with each other by reference to these intervals; no accurate comparison was possible between two notes produced on different days. Sauveur first pointed out that the character of the note depends on the number of vibrations in a given period made by the sounding body. The difficulty was to count them in the grave notes, where they are the least rapid. If we take two organ-pipes which sound in perfect unison, and shorten one of them a little, it is well known to organ-builders that a curious pulsing sound, swelling and falling alternately at regular intervals, accompanies the notes when they are both sounded together. These pulses are called beats, and Sauveur explained them substantially as we do, by the periodic coincidences and oppositions of the condensed parts of the two vibratory air-columns. When the pipes produce concurrent effects, the loud pulse is heard; when they oppose each other, the sound dies away. The times of these coincidences and oppositions can be calculated. If the ratio of the numbers of vibrations (which depend on the length of the air-columns) be, let us say, as 8 : 9, there will be a beat at every interval of eight vibrations of the one and nine of the other. If 16 be heard in a second, there must have been 128 vibrations of the one column and 144 of the other in the same time. Sauveur found in this way that the grave *do* of an 8-foot organ-pipe makes 122 vibrations per second. It is a curious illustration of the importance of his discovery and of the difficulty of comparisons between the musics of different periods which are founded on anything but the number of the vibrations, that the note that now goes by the same musical name (the

grave *do* of the violoncello at 15° C.) corresponds in pairs to 130½ vibrations. Chladni proposed 128 as a number readily subdivisible. The suggestion has been generally followed in physical discussions. The French standard was fixed by ministerial decree in February, 1859, and adopted at the opera at Vienna, and officially in Russia three years later. The English standard is 133½, and the German 132, vibrations. There has been a gradual rise at the Italian Opera in Paris from the days of Sauveur until the standard number came to be 134½ just before it was reduced by decree. Scheibler showed that one note had stood successively for 867, 872, 878, 880, and 889 vibrations in the course of thirty years of the present century.

* * * * * * * * *

"The experiment suggested by Sir John Herschell gives us two sounds resulting in silence. Let us imagine a tube like a narrow rectangle, with two holes in the middle of the two longer sides for the insertion of long tubes perpendicular to them. On the one side of these tubes the whole arrangement is permanent, on the other the rectangle has a sliding part, as in a trombone, so that we may draw it out or push it in at pleasure. The tubings, therefore, which are at first of equal lengths to right and left of the insertions, may become unequal, and by any desired amount.

"At the open end of the one insertion let a tuning-fork be struck; at the other, which should be far enough removed to make it impossible to hear the tuning-fork without the help of the apparatus, let the observer place his ear. The vibrations travel down the first insertion, but divide into two halves to right and left of the opening into the rectangle.

"After pursuing their equal paths, they meet at the opening opposite, and pass down the second insertion-pipe to make a distinct and loud impression on the drum of the ear.

"When the right-hand tube is a little drawn out, the sound is enfeebled; when it is drawn out a certain length, it is not heard at all. The difference is half a wave's length of air, corresponding to the note sounded.

"Drawn out a little farther, the sound grows again, till, when it has got twice as far as at first, it is heard just as distinctly as before the tube was pulled out at all.

"If we cut off one of those interfering air-columns from passing into the second insertion-tube, the sound is heard half as loud as in the first case.

"The silence, the double sound, and all the shades of intermediate vibrations which theory requires are exhibited in the experiment."

The harmony and discord of sounds is admirably shown by another apparatus, constructed by Pichler. It is true that the idea of such an apparatus is not new, because M. Lissajous has shown the same facts with tuning-forks, to which mirrors were attached to reflect the rays from the electric, or oxy-hydrogen, or oil-lamp light.

Pichler's apparatus is unique. It consists of two harmonium-reeds with mirrors, one perpendicular and the other horizontal. Upon the first falls a bright beam of light from a proper lens, and this being vibrated or sounded, gives a perpendicular line of light; the horizontal reed and mirror give a horizontal line. These notes are tuned as nearly as possible in unison, and when they are sounded together, the ray of light reflected from the perpendicular reed to the horizontal one resolves itself into a compound motion, which gives the form of rings of light, rotating in the most exquisite manner.

There cannot be a more perfect expression of human harmony than the

FIG. 453.—*Pichler's Harmony and Discord Apparatus.*

presentation of "a plain gold ring." These two sounds in harmony give the figure of a ring, which may change, like earthly affairs, to discord. When the



FIG. 454.—*Arrangement of the Reeds and Mirrors to reflect the Light.*

two notes are vibrated in another phase, a somewhat confused picture is observed on the disc, which changes again to a "true lover's knot" as the vibrations are altered thus:

C natural, C bass, an 8-foot note, in unison with another of the same kind, gives the ring of light.

E, $\frac{1}{8}$, gives the figure of 8—two rings.

G, $\frac{1}{8}$,—"true lover's knot, or three rings.

Thus the whole octave may be traced out with beautiful figures, all differing from each other.

Harmony is heard and seen, and so also is *discord.*

THE TRANSMISSION OF SOUNDS THROUGH GASEOUS, LIQUID, AND SOLID MEDIA.

The progress of sound through air and the manner in which it travels has already been discussed; it is only necessary to speak of the velocity of sound, in which the relation between density and elasticity is well shown. As the propagation of sonorous waves is gradual, sound requires time for its transmission from one place to another. According to the French and Dutch philosophers, the velocity of sound at 26·6° C. is 1,140 feet per second. At the freezing temperature, 0° C., the velocity is diminished to 1,090 feet per second: here the density is increased, the elasticity of the air remaining the same. An increase in the temperature of the air equal to 1° causes a corresponding increase of 1·14 feet per second in the velocity of sound: here the density being diminished, the elasticity remains the same. The velocity is directly proportional to the square root of the elasticity of the air, and inversely as the square root of the density.

Sound, in fact, travels through different media with very different degrees of velocity; thus, starting with air as *unity* or one, the following velocities have been determined:

Distilled water . .	4·5	Laplace.	Brass	10·5	Laplace.
Sea-water . .	4·7	"	Copper . .	12·0	Chladni.
Tin	7·5	Chladni.	Hammered iron .	17·0	"
Silver	9·0		Glass . . .	17·0	"
Cast iron . .	10·0	Bibot.	Wood . .	11·0 to 17·0	"

It is apparent from the above table that the velocity does not depend only on the density of the body transmitting the sound, but in a greater degree on its elasticity.

Tyndall shows from his own observations that the intensity of sound depends on the density of the air in which it is *generated*, and not on that of the air in which it is heard. As an illustration, he supposes the case of two cannon with equal charges, the one fired from a lofty mountain, such as the summit of Mont Blanc, and the other from Chamouni; the latter, being fired in heavy air, may be heard above, whilst the former, being fired in rarefied air, is unheard below. He further remarks:

"There is no *mistake* more common than to suppose the velocity of sound to be augmented by density. The mistake has arisen from a misconception of the fact that in solids and liquids the velocity is greater than in gases.

"But it is the high elasticity of those bodies *in relation to their density* that causes sound to pass rapidly through them.

"Other things remaining the same, an augmentation of density always produces a diminution of velocity."

The laws that govern the propagation of sound are very similar to those which rule the progress of light.

The intensity of sound is in the inverse ratio of the square of the distance of the sonorous body from the ear.

If one bell affords a certain amount of sound at a distance of 100 ft., it will require four bells of equal power to affect the auditory nerves to the same amount at 200 ft., or double the distance.

It is said that an experienced general, walking on the heights of Dover, predicted that a great battle was being fought, from the sounds which his experienced ear detected; and taking down the hour and date, they tallied exactly with the time of the hottest part of the firing on the field of Waterloo. The higher the waves of water, the louder the roar as they dash on the rocky shore. The intensity of sound is proportional to the square of the amplitude or largeness of the undulation, and also to the square of its maximum velocity; it is also modified by the motion of the air. Sounds are propagated better in calm than in stormy weather, also with more intensity in the direction of the wind than in the contrary direction.

A modification of the law, that the intensity of sound varies inversely as the square of the distance, takes place when sound is caused to travel through long smooth tubes. The sound moves like the rings produced in a pool of water by a falling stone: they are no longer spread out laterally until they fade away to silence, but are transmitted without any perceptible alteration from one end of the tube to the other.

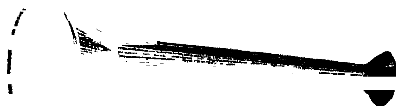


FIG. 455.—*The Speaking-Trumpet.*

The common speaking-trumpet, which is a conical metal tube, made wide at one end like a funnel, called the "bell," and furnished with a mouthpiece at the other, is of great use to captains of vessels and pilots in giving the necessary orders during the noise that prevails in stormy weather. The reflection of the sound-waves from the sides of the tube, and the positive direction given to them, may probably explain the cause of the strengthening of the voice, which is as much increased as if the trumpet represented the mouth of a giant with his lips wide open.

The empty water-pipes of Paris were placed at the disposal of Biot, the great French philosopher, and though he spoke in a whisper, his voice was distinctly heard through a distance of upwards of 3,000 yards, a range which any experienced rifleman would fully appreciate.

A hollow tube placed on the region of the heart or lungs, and applied to the experienced ear of a medical man, enables him to form an opinion of the state of these organs, the instrument being called the Stethoscope.

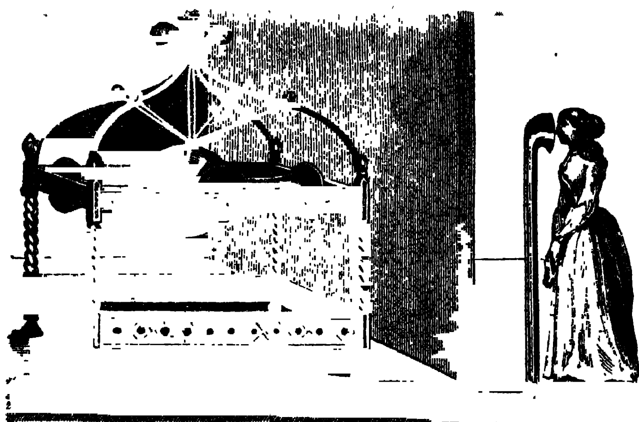


FIG. 456.—*The Invisible Girl.*

The practical application of Biot's experiment was soon made in England, and now there is hardly an office (where the clerks have to sit on different floors) which is not fitted with speaking-tubes.

The cut (Fig. 432, p. 473) at the head of the chapter on acoustics, graphically depicts the old story of the speaking head of Albertus Magnus, which is said to have been dashed to pieces by his worthy pupil, Thomas Aquinas, perhaps because, knowing the voice, he would not have his understanding insulted with such a shallow trick. Here again the hollow tube conveys the sound from the mouth of the concealed master to the ear of his warm-tempered pupil.

The Anthropoglossos, or speaking head, and "human voice," exhibited in London as a genuine mechanical talking head, which they pretended to wind up, was, of course, only a modification of the above old story, and not one-quarter so clever as the famous invisible girl, which really puzzled the cockney wiseacres many years ago.

The cut (Fig. 456) explains itself, and clearly shows the hollow tube passing under the floor. At one end is a girl, who receives and answers questions; at the other, and suspended in a sort of ornamental bedstead, are the trumpets attached to a hollow globe, as delineated in Fig. 457, and demonstrating that the main pipe came up one of the posts of the bedstead, and then was connected with two pipes placed opposite the mouths of the trumpets.

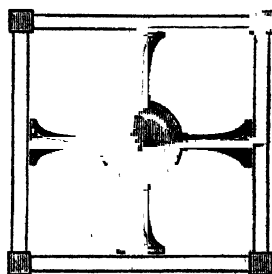


Fig. 457. *The Globe and Trumpets.*

At the Polytechnic a speaking head was shown, and explained to be due to the same kind of arrangement, the writer's assistant being concealed in an adjoining apartment, to which a gutta-percha pipe passed, terminating in a hollow head with a movable jaw.

When the eyes are deceived simultaneously

with the ears, acoustic illusions are greatly enhanced; thus, a striking bell deprived of its clapper, and placed *upon* the table, apparently yields a sound when the stud is pressed down, whereas it is the foot pressing on the stud of another striking bell *under* the table that really yields the sound.

Dulong's table of the velocity of sound per second through air and some of the gases, at a temperature of 0° C., may well complete this part of the subject.

	Velocity.		Velocity.
Air . .	1,092 feet	Carbonic oxide .	1,107 feet
Oxygen . .	1,040 „	Protoxide of Nitrogen .	859 „
Hydrogen . .	4,164 „	Olefiant gas .	1,030 „
Carbonic acid .	858 „		

Transmission of Sound through Liquids.

The celebrated Dr. Franklin ascertained that liquids conducted sound, by placing an assistant half a mile from himself, who was directed to continue to strike two stones together under the water. The doctor did not take a "header," though he placed his own head under water, and, it is said, distinctly heard the sound caused by the knocking together of the stones.

Colladon and Sturm's experiments on and in the Lake of Geneva have always been quoted as most excellent and trustworthy. They determined that the velocity of sound in water was 4,708 feet per second; subsequently Wertheim determined that the velocity of sound in the water of the Seine, at a temperature of 15° C., was 4,714 feet per second, or six feet per second faster than that recorded by Colladon and Sturm. This difference was probably due to temperature, the water of the Lake of Geneva being colder at the time than that of the River Seine.

Salts dissolved in water increase the velocity of sound, and especially chloride of calcium. The velocity of sound in water increases, like that in the air, with the temperature, and sound was found to travel at the rate of 5,657 feet per second, at a temperature of 60° C., through the water of the Seine.

Transmission of Sound through Solid Conductors.

Wertheim's table is a good preface to Wheatstone's admirable experiments.

Name of Metal.	At 20° C.	At 100° C.	At 200° C.
Lead . . .	4,030	3,951	—
Gold . . .	5,717	5,640	5,691
Silver . . .	8,553	8,658	8,127
Copper . . .	11,666	10,802	9,690
Platinum . .	8,815	8,437	8,079
Iron . . .	16,822	17,386	15,483
Iron wire . .	16,130	16,728	—
Cast steel . .	16,357	16,153	15,709
Steel wire, English	15,470	17,201	16,394
Steel wire . .	16,023	16,443	—

In September, 1831, Mr. Charles Wheatstone recorded the following in the "Journal of the Royal Institution:"

"The fact of the transmission of sound through solid bodies, as when a stick or a metal rod is placed at one extremity to the ear and is struck or scratched at the other end, did not escape the observation of the ancient philosophers; but it was for a long time erroneously supposed that an aëriform medium was alone capable of receiving sonorous impressions, and, in conformity with this opinion, Lord Bacon, when noticing this experiment, assumes that the sound is propagated by spirits contained in the pores of the body. The first correct observations on this subject appear to have been made by Dr. Hooke, in 1667, who made an experiment with an extended wire of sufficient length to observe that the sound was propagated far swifter through the wire than through the air. Professor Wunsch, of Berlin, made, in 1778, a similar experiment, substituting 1,728 feet of wooden laths for the wire, and confirmed Dr. Hooke's results. Other results of a similar nature were subsequently made by Herholt, and Rafn Hassenfratz, and Gay Lussac, &c.; but the first direct observations of the actual velocity of sound through solid conductors were made by Biot, assisted at different times by Bouvard and Martin. These experiments were made on the sides of the iron conduit-pipes of Paris through the length of 951 mètres 25 centimètres, and the mean result of two observations made in different ways gave 3,459 mètres, or 11,090 feet, per second for the velocity of sound in cast iron. Previously to these last-mentioned experiments, Chladni had in an ingenious manner inferred the velocity of sound in different solid substances, and his results are fully confirmed by calculations from other grounds. His method was founded on Newton's demonstrations that sound travels through a space of a given length filled with air in the same time that a column of air of the same length contained in a tube open at both ends makes a single vibration. His discovery of the longitudinal vibrations of solid bodies, which are exactly analagous to the ordinary vibrations of columns of air, enabled him to apply this proposition to solid bodies, and to establish the general law that sound is propagated through an elastic substance, in which this substance makes one longitudinal vibration. In this manner he ascertained the velocities of sound in the following substances among others: tin, 7,800; silver, 9,300; copper, 12,500; glass and iron, 17,500; and various woods, from 11,000 to 18,000 feet in a second. From the experiments of M. Perotti it would appear that the intensity with which sound is communicated through solid matters is nearly in proportion to the velocity of its transmission. In all the experiments above alluded to the sounds transmitted were either mere noises, such as the blow of a hammer, or, as in Herholt and Rafn's experiments, a single musical sound produced by striking a silver spoon attached to one end of the conducting-wire, and in no case were any means employed for the subsequent augmentation of the transmitted sound. I believe that, previously to the experiments which I commenced in 1820, none had been made on the transmission of the modulated sounds of musical instruments, nor had it been shown that sonorous undulations propagated through solid linear conductors of considerable length were capable of exciting in surfaces with which they were in connection, a quantity of vibratory motion sufficient to be powerfully audible when communicated through the air.

"The first experiments of this kind which I made were publicly exhibited in 1821, and notices of them are to be found in the "Literary Gazette,"

"Ackerman's Repository," and other periodicals of that year. On June 30, 1823, a paper of mine was read by M. Arago, at the Academy of Sciences at Paris, in which I mentioned those experiments and a variety of others relating to the passage of sound through rectilinear conductors. I propose in the present instance to give a more complete detail of these experiments than I have yet published, and, at the same time, to add what additional facts my subsequent experience has furnished me with on the same subject.

"Sonorous bodies are audible (the extent being supposed equal) in proportion to the quantity of their vibratory surfaces. Thus a plate of glass or metal is capable of producing powerful sounds without accessory means; but the sound of vibrating bodies of smaller dimensions, such as insulated strings or tuning-forks, are scarcely audible at a moderate distance from the ear, but the sounds of the latter are capable of considerable augmentation when communicated to surfaces, as when they are placed to a table or the sounding-board of a musical instrument.

"There are several circumstances which influence the intensity of the resonance of a sounding-board; the principal of these is the plane in which the vibrations of the sounding body are made with respect to the reciprocating surface. Thus its vibrations may be so communicated as to be perpendicular and normal to the surface in which the sound is the greatest augmented; or they may be tangential to, or in the same plane with, the surface when the sound is the most feeble. The first of the causes may be illustrated by placing a vibratory tuning-fork perpendicular to the surface of a flat board, and the second by placing it perpendicular to one of the edges of the board. In intermediate positions, viz., when the vibrations are communicated obliquely to the surface, the sound will be found to have intermediate degrees of intensity.

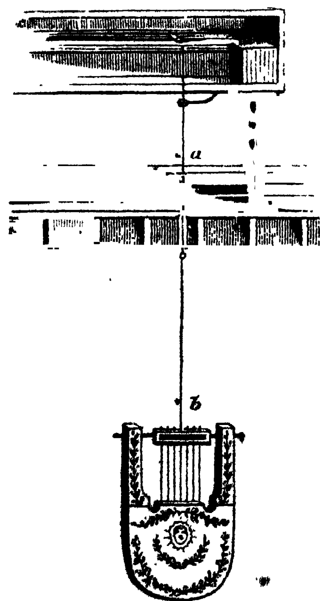


FIG. 458.

"These facts, which the extensive investigations of Savart place in full evidence, being understood, the peculiarities of the sounding-boards of various musical instruments admit of easy explanation. The sounding-board of the pianoforte is better disposed than that of any other stringed instrument, as the planes of the vibrations of the strings are, on account of the direction in which they are struck by the hammers, always perpendicular to its surface. The difference of intensity when a string vibrates in this way and when it vibrates parallel to the surfaces is very obvious, and may be easily tried by striking it with the finger in these directions. There is no other instrument now in use in which the strings make their vibrations perpendicular to the sounding-board.

"Tuning-forks are the most convenient instruments for making experiments on the transmission of sound, because their vibrations are almost inaudible by themselves, and only become strongly audible when augmented by resonant surfaces. In the first public experiment

I made, in 1821, the reciprocating instrument, which was the representation of the ancient lyre, was so constructed as to produce tangential vibrations. The tones were far inferior to what I have since been able to produce. The transmitted sounds are not sensibly impaired when the wire is separated at several places and the disunited parts fastened together by mechanical contact. The woodcut (Fig. 458) shows the arrangement.

"But if the apparatus be intended as a fixture, it will be easier and better to use one piece of wire. The wire consisted of four portions: the first touched the sounding-board of the instrument and reached half-way to the floor; the second passed through the insulating-tube in the floor, and terminated in the ceiling of the room below in a hook; the third part was attached to the lyre at the place marked at the dotted end of the line on the sounding-board. Each of the parts was allowed to overlap at *a* and *b*, and was fastened by means of a screw-nut.

"The sounds of an instrument may be at the same time transmitted to more places than one; for instance, communications may be made from a square pianoforte to a resounding instrument above and to another below. In a similar manner the sounds of an entire orchestra may be transmitted, viz., by connecting the end of the wire conductor with a properly constructed sounding-board, so placed as to resound to all the instruments.

"The effect of an experiment of this kind is very pleasing: the sounds, indeed, have so little intensity as scarcely to be heard at a distance from the reciprocating instrument; but on placing the ear close to it, a diminutive band is heard, in which all the instruments preserve their distinctive qualities, and *pianos* and *fortes*, *crescendos* and *diminuendos*, their relative contrasts. Compared with an ordinary band heard at a distance through the air, the effect is as a landscape seen in miniature beauty through a concave lens as compared with the same view viewed by the ordinary vision through a murky atmosphere.

"In the preceding experiments on the transmission of sound through solid bodies the conductors have been represented as straight; but, though sound is transmitted the more readily through straight conductors, it will yet pass, though with diminished intensity, through rods with angular and curved bendings. If a vibrating tuning-fork be placed at one end of a straight brass rod, the other end of which rests perpendicularly upon a sounding-board, the vibrations will, in accordance with what has been above stated, be powerfully transmitted. On gradually bending the rod at any part of its length, while the vibrations of the tuning-fork are kept in the same plane with the angle of the bent rod, the transmitted sound will progressively decrease in intensity, and will become very feeble when the angle becomes a right one: as the bending is continued, so as to make the angle between the two parts of the rod more acute, the intensity of the sound will increase in the same order in which it had before diminished, and when the two parts of the rod are nearly parallel, the sound will be nearly as loud as when the transmission was rectilinear. If, during the gradual bending of the rod, the plane of the vibrations of the tuning-fork be perpendicular to the plane of the angle made by the two parts of the rod, the same changes will be observed, but in a more obvious manner than in the former case; and when the angle becomes a right one, the sound will be scarcely perceptible. At intermediate inclinations of the two planes the gradations of intensity occasioned by the bending of the rod will be found to be intermediate. The changes of intensity dependent on the

variation of the angles of the two planes may be instructively shown by bending the rod permanently to a right angle, and placing, as before, the stem of a tuning-fork so as to form the prolongation of one of the parts of the rod, the other part of the rod resting on the sounding-board. On gradually turning the tuning-fork round the axis of its stem, without inclining it to the rod, the plane of the vibrations will assume every angle with respect to the plane in which the two parts of the rod are bent. During the revolution it will be observed that when the planes coincide the intensity will be at its maximum; and when they are perpendicular to each other, at its minimum. Thus, supposing the sound to commence when the two planes are parallel, it will gradually diminish until they make an angle of 90°; it will then increase in the same changes of intensity in an inverted order, until it acquires its maximum at 180°; it will again decrease between this and 270°, and increase until it arrives at its first position 0°.

"If the stem of the tuning-fork be placed perpendicularly on the side of a conducting-rod resting on a sounding-board, the same phenomena may be observed; the stem of the tuning-fork is, in fact, a short conductor, forming a right angle with the rod. Were it necessary for the transmission of sound that the undulations should propagate themselves rectilinearly, it is obvious that they would not pass through a bent rod; and, on the other hand, had they the property of diffusing themselves equally in all directions, we should not observe any difference of intensity in the experiments above noticed.

"These experiments lead us to conclude that sound diffuses itself in all directions, though unequally; that it is communicated more readily in the plane in which the original vibrations are made, and that the greatest degree of intensity is in the direction of these vibrations.

"To extend these experiments much further would be attended with some difficulties; but, as the velocity of sound is much greater in solid substances than in air, it is not improbable that the transmission of sound through solid conductors and its subsequent reciprocation may hereafter be applied to many useful purposes. Sound travels through the air at the rate of 1,142 feet per second; but it is communicated through iron wire, glass, cane, or deal wood rods with the velocity of about 18,000 feet per second, so that it would travel the distance of 200 miles in less than a minute.

"When sound is allowed to diffuse itself in all directions as from a centre, its intensity, according to theory, decreases as the square of the distance increases; but, if it be confined to one rectilinear direction, no diminution of intensity ought to take place; but this is on the supposition that the conducting body possesses perfect homogeneity and is uniform in its structure,—conditions which never obtain in our actual experiments. Could any conducting substance be rendered perfectly equal in density and elasticity, so as to allow the undulations to proceed with a uniform velocity without any reflections or interferences, it would be as easy to transmit sounds through such conductors from Aberdeen to London as it is now to establish a communication from one chamber to another. Whether any substance can be rendered thus homögeneous and uniform remains for future philosophers to determine."

At the Polytechnic Sir Charles Wheatstone very kindly superintended the arrangements of the rods passing through various apartments from the basement to the lecture-room, and subsequently had the pleasure of seeing the manner in which his beautiful experiments with four instruments and the sounding-boards of four harps, called the "telephonic concert," were appre-

ciated by Her Majesty, the late lamented Prince Consort, H.R.H. the Prince of Wales, and the younger members of the Royal Family.

The efforts made by the writer to give refined science at the Polytechnic to the public at that time were not successful in a monetary point of view, and he lost his private patrimony trying to effect this object, as sole proprietor of that establishment. Grown wiser by experience, he is *obliged* to cater differently, and the institution has flourished and is now most prosperous, and the author hopes, with the blessing of the Highest, it may long continue to be so.

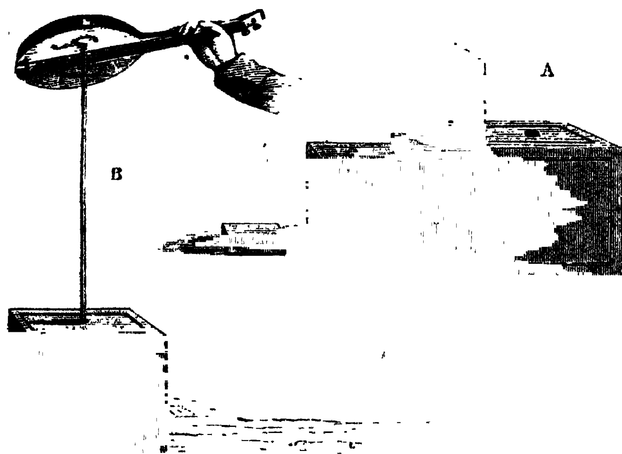


FIG. 459.—*The Miniature Telephonic Concert.*

B, stick passed through the boxes A, and touching the musical box at one end, whilst the other is pressed against the sounding-board of some instrument.

A very pretty illustration of Wheatstone's experiments with the transmission of vibrations through solid conductors may be performed by constructing a series of boxes (A, Fig. 459) to fit one within the other, the last to contain a musical box resting on a few folds of baize. The latter, whilst playing, is shut up in the other boxes, and the sound gradually dies away; it is, however, immediately brought back into the room by thrusting a long wooden rod through the holes made in the boxes, and, of course, superimposed upon each other. Directly the end of the rod touches the musical box, the hand instantly feels the vibrations, and the sound is now partially heard, becoming quite loud when the sounding-board of a violin, or, better still, that of a harp lute (B, Fig. 459), is pressed lightly down on the end of the wooden rod.

Gas and water are supplied to our dwellings, and may be turned on or off at pleasure; so it is with the musical sounds,—they become audible or inaudible as the sounding-board is applied or removed.

Whilst alluding to ingenious and pleasing acoustic experiments, it may be well to mention here the very pretty toy called "The Piping Bullfinch," which was so much admired in the Swiss Court of the Great London Exhibition of 1862. When a spring is touched, a little model of a bullfinch, with feathers,

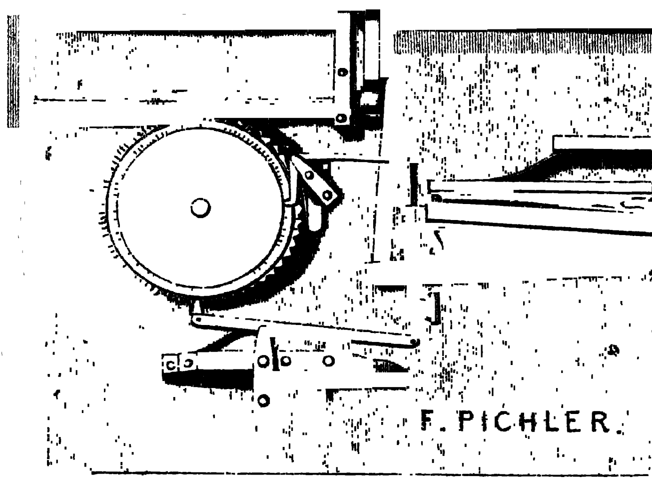


FIG. 460.—*The Enlarged Model of the interior of the Mechanism called the Piping Bullfinch,*

The motion being produced by an endless screw, turned by the hand instead of by clockwork, as in the Piping Bullfinch toy.

moving wings, and beak, pops out of the box, and pipes almost as naturally as a living songster.

The listener imagines that the sound comes from the beak and from the body of the bird; but that is not the case: the box would sing just as well without the bird as with it—the bird serves to engage the eye, the music the ear. The sound comes from a small pipe, provided with a piston, which continually shortens and lengthens the tube. The action of the piston is secured by a lever, which is moved as the studs of a barrel (like a barrel organ) come round and touch it. A regular piping tune is set out in studs on the barrel, and the pipe which emits the sound is exactly like the pipes sold in the streets, only instead of the column being shortened and lengthened by immersion in water, it is done with a piston, and the pipe supplied with air from a small bellows.

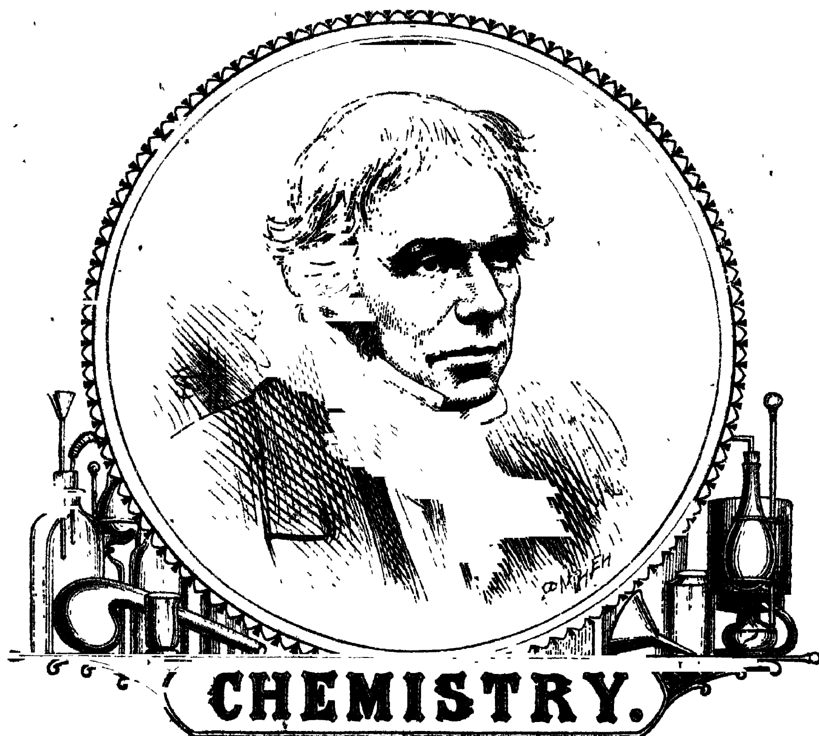


FIG. 461.—*Portrait and Signature of Faraday.*

The former from a photograph by Mr. James How, successor to Knight and Co., of Foster Lane, Cheapside.

CHEMISTRY.

THE son of a smith—the apprentice of a bookseller and bookbinder in Blandford Street, Manchester Square—a journeyman at some other place of business—and subsequently engaged by Sir Humphrey Davy at weekly wages—no lordly patronage heralded the approach of FARADAY: he was indebted to no one except another scientific man, like himself an humble beginner—a chemist's apprentice, a washer of bottles. And yet he lived to make a name that few have or will ever be able to achieve. What does he say of himself?

"I was formerly a bookseller and binder, but am now turned '*philosopher*,' which happened thus: whilst an apprentice, I for amusement learned a little chemistry and other parts of philosophy, and felt an earnest desire to proceed in that way further. After being a journeyman for six months under a disagreeable master, I gave up my business, and through the interest of *one* Sir H. Davy filled the situation of chemical assistant to the Royal Institution of Great Britain, in which office I now remain, and where I am constantly employed in observing the works of Nature, and tracing the manner in which she directs the order and arrangement of the world."*

On the 18th March, 1813, it was resolved "That Michael Faraday be engaged to fill the situation lately occupied by Mr. Payne, on the same terms."

Faraday accompanied Sir H. Davy to Rome, and was re-engaged by the Royal Institution managers on the 15th May, 1815; and as his first private and original sacrifices of time, energy, and talent were made to "Chemistry," his portrait is placed at the head of this section.

What income Faraday derived from the Royal Institution is not exactly known. The writer has heard the late Mr. Robert Murray say that he had only £200 per annum, and apartments, for a very long period; until somebody suggested that he was no longer an assistant, but a "master," and ought to be paid as a "philosopher." Much or little, it affected not Faraday: his private charities and good deeds are known only to the Great Giver of all things.

The "Mechanic's Magazine," speaking in the hearty truthfulness of independent journalism, said, in October, 1859, that which carried conviction to the hearts of many who see how often science is degraded into "flunkeyism," instead of being elevated to "Faradism,"—

"The other characteristic of our time to which we refer is its boldness, comprehensiveness, and certainty of mental inquiry, which expresses itself in its favourite term—science. We had a notable example of this in the speech of the Prince Consort at Aberdeen, which we reprinted in our journal a fortnight ago. It was a fine specimen of the best mind among us. What choice, pure English the language was, and of such delicate precision and beauty! What graceful personal modesty the speaker showed! How full the discourse was of the old German solidity and seriousness of purpose, that marks all the German people, whether in the old Fatherland or in Angleland. The term 'science' in this address is made to embrace the whole range of the human mind. There are three objects of man's contemplation and inquiry—Nature, Man, God. The human mind has two methods of working—analysis and synthesis. It dissects into parts, observes, examines, reasons about each part; or intuitively it grasps the law that binds and controls the parts and knits them into a whole. All follow this method, says the Prince—the child, the man of mere practical instinct, or the philosopher. The child, as soon as his first surprise and ecstacy at the new universe subside a little, begins to ask the *how* and *why* of things. He practises his analysis by pulling his toy to pieces to discover how it works; or he performs a splendid generalization; as, for example, when the fire burns him, he affirms to himself that fire burns in every instance, at all places and times, though he has only experienced one instance of its burning power. The practical man is instinctively impelled to philosophize, in his rough, homespun method, on the facts he is brought into contact

* Tyndall "On Faraday as a Discoverer."

with. But the philosopher, by stronger instinct and by conscious self-determination, directs his eye to every part of the great All.

"Science, the Prince hints, has been of slow growth in England, partly because we English are so wedded to what is immediately useful, what immediately shows a return in pounds, shillings, and pence; and partly from our excessive devotion to antiquity, that 'till of late has almost systematically excluded from our school and university education' the great subjects and the results of modern inquiry, while it has given to antique things that liveliness of interest we feel all through life in the subjects we studied in early years.

"The illustrious speaker lays great stress on the *absence* of all *professionalism* and *officialism* from science. *Knowledge, in his eyes, has no aristocracy or priesthood.* Its *genuine* students are not '*a secret confraternity of men jealously guarding the mysteries of their profession;*' their activity is 'the republican activity of the Roman Forum.' But if boldness and freedom, the Prince reminds us, are the characteristics of the philosopher, equally so is reverence. The more he explores the more he becomes aware of '*the boundlessness of the universe, whose confines appear ever to retreat before our finite minds.*' True thinkers are '*not conceited pedants, wrapped up in their own mysterious importance, but humble inquirers after truth; not God-defying Titans, but reverent, pious pilgrims towards a Holy Land—God's truth—God's laws, as manifested in His works, in His creation.*'"

The imponderable forces have already been dealt with, and yet there remain those of Gravitation, Cohesion, Adhesion, and Chemical Action. To speak of the first would be to enter upon the science of astronomy, which is impossible in this work; it is sufficient to refer the reader to the first lines of the epitaph under the statue of Sir Isaac Newton:

HERE LIES INTERRED
ISAAC NEWTON, KNIGHT,
WHO,
WITH AN ENERGY OF MIND ALMOST DIVINE,
GUIDED BY THE LIGHT OF MATHEMATICS PURELY HIS OWN,
FIRST DEMONSTRATED
THE MOTIONS AND FIGURES OF THE PLANETS,
THE PATHS OF THE COMETS,
AND THE CAUSES OF THE TIDES.

The reader working out only the philosophy of the last lines will soon acquire a knowledge of the power supposed to exist, and which by universal consent is called Gravitation.

Newton was born on the 25th December, 1642, and died on the 20th March, 1726. Gravity is defined as that force which tends to make bodies move downwards towards the centre of the earth, and which prevents their being moved upwards. If the atmosphere surrounding our earth were not fixed to it by the invisible chain of gravitation, it would have expanded long ago into space, and no human beings with their present organization would have been left to tell the tale of desertion, for all would have perished for want of air.

The amount of downward force which causes a body to gravitate to the earth is called its "weight."

For the sake of comparison it was found necessary to fix some "standard" to which the weights of different substances might be referred.

Water was selected, because it is to be found in all places and in all seasons: its presence is, in fact, universal; and therefore a pound avoirdupois of water, containing 7,000 grains, of which each 252·458 grains are equal to

one cubic inch, is taken as the fixed and determined standard,—provided always that it be estimated at a temperature of 62° F., the barometer being at 30 inches.

As water is taken as the standard for the determination of the specific gravity of solids and liquids, so air at 62° F. and 30 in. barometer is taken for that of all gaseous bodies.

The mode of determining the specific gravity of solids is very simple:

1. Weigh the solid substance in air;

2. Also in water, taking care to prevent air-bubbles adhering to the substance; and this the writer finds is entirely prevented (where the substance is insoluble in alcohol) by dipping the solid into alcohol, and then into several waters, at last placing it in the vessel of water in which the specific gravity is to be ascertained.

3. Divide the gross weight by the loss of weight of water, and the quotient gives the specific gravity.

The specific gravity of liquids is ascertained *directly* by first adjusting a glass bottle (the weight of which is balanced by a counterpoise) to hold 1,000 grains: if the same bottle be filled with alcohol, it weighs less than water, viz., 792 grains; if filled with oil of vitriol, it weighs more than the same bulk of water, viz., 1,845 grains. The exact weight is the reading, and no calculation is required.

The determination of the specific gravity of a gas is founded on the same principles, but the most elaborate precautions must be taken. A given volume of air, such as that contained in a wine-flask, is first weighed; then it is emptied by the air-pump and weighed again; lastly, it is weighed full of the gas of which it is required to ascertain the specific gravity. A simple rule-of-three sum determines the question—that is, roughly: to perform the experiment accurately, the precautions insisted on by Regnault ("Annals de Chemie," III., xiv. 211) must be taken.

Daniell defines cohesion to be homogeneous attraction: ὁμὸς like, and γένος kind—alike in nature of properties. Two surfaces of lead cohere, provided that they are perfectly clean and bright; two bars of iron sufficiently heated may be welded together by hammering or any other kind of mechanical pressure or force. If metallic contact between the two bars be not well secured by proper handicraft, the weld is imperfect, and the two surfaces of iron do not cohere, but separate on the application of slight mechanical force. A drop of dew on a cabbage-leaf is an excellent illustration of cohesive power in a liquid; and this property has been turned to a good account by Professor Tomlinson, and subsequently by Dr. Moffat, of Glasgow, who has quite dignified an otherwise humble department of physical truth by his efforts to make the new art of Oleography popular.

These oleographs (Fig. 462) indicate special figures always assumed by any particles of oil or other fluids of a kindred nature; therefore they become guides to direct the analyst, who, by consulting these figures, can ascertain whether the oil, tallow, lard, or other kind of grease is really what it purports to be.

Professor Tomlinson was the first to call attention to this peculiar class of experiments, and his original discoveries have been greatly extended by Dr. R. Carter, Moffat Lecturer on Chemistry, Glasgow, to whom the writer is indebted for the originals from which the cuts (Fig. 462) are taken. The latter gentleman's paper in the "Chemical News" (Vol. XVIII., No. 473) is so very concise and explanatory of the whole process, that it is given here

nearly *in extenso*. The process will remind the reader of the art of marbling paper, which, like the oleographic process, is one of the most ingenious and amusing that can be introduced to a general audience.



FIG. 462.—*Oleographs of Tallow and Lard, taken by Dr. Moffat*

OLEOGRAPHY: BEING A PROCESS FOR THE UTILIZATION OF TOMLINSON'S COHESION FIGURES.

"Chemists are aware that most kinds of oil when poured on water spread over its surface, and sooner or later break into variegated patterns, some of which are of great beauty. When we make a few experiments in this direction, attention is attracted to the regularity of the forms assumed, and further, that almost all the common oils give different models of patchwork according to the length of time that the oils are exposed. Experiments conducted in my laboratory show that from the construction of the oil-film we can with considerable certainty determine the kind of oil examined, and also its genuineness. A drop of pure sperm oil let fall on a basin or plate full of water quickly becomes an enlarged circular film of several inches diameter, breaking up near the edges into small round holes. This takes place in about sixty seconds in the case of pure sperm. The centre of the patch is at the same time filled with little holes, somewhat smaller than those at the edges. At two minutes all the little openings are considerably expanded, and they continue to extend until after a lapse of thirty minutes or so, when the oil is broken up and detached. There is value attached to this simple test. Green rape-oil breaks up slowly, more so than sperm; but after sixty seconds its pattern is different, the circles being large and beautifully defined. Purified rape oil becomes much larger in the pattern circles than green rape in the same time. Lucca olive gives in one minute a large representation, in two minutes an extraordinary development, and in three minutes a very large likeness.

"Green olive, on the other hand, gives but a small pattern in one minute, and conducts itself quite at variance with Lucca olive. Again, seal and castor oil give forms which are very small compared with many oils. In making these observations it is necessary to attend to the size of the drop of oil, the height it falls, the force with which it does so, the perfect purity of the

cold water, and the stillness of the water at the time. To make the experiment, proceed as follows: From a small dry burette drawn out to a fine point, filled up to a certain mark with the oil, cautiously let fall a single drop at four inches height upon the centre of the water contained in a common soup-plate or glass basin. We shall assume that Lucca olive is taken. The drop should at once spread about four inches on the water circularly. If it does not do so at once, then the plate or the water is not clean, and the water is to be poured out, the plate well washed with water, and again filled. All rubbing with towels is to be avoided. At thirty seconds the appearance of the representation is very lovely, having all the similitude of crochet-work. To give definitions of its many figures, I would need to have Roget's 'Thesaurus of English Words and Phrases' before me. It is needless at present to enumerate the diversity of these oil-films at different periods of time. Tomlinson has enriched science by his masterly descriptions of them. He has done more in this department than any man. To him is due many discoveries in experimental philosophy—facts of the greatest value and importance. It is to him that I would ascribe my recent discovery of the utilization of the cohesion figures of oil on water. Had it not been for a knowledge of the facts connected with his researches in this beautiful and interesting department of science, then in all probability the oil figures would have remained what they are—beautiful to look at, but transient in the extreme. The eye becomes tutored and experienced to these forms, so that it can readily determine the kind of oil under examination. I do not aver this to be the fact in all cases. In very many instances it is so. Indeed, in all that have come under my notice this is the conclusion arrived at. Perfect concordance of results is, I am almost certain, to be obtained when the size of the drop of oil and all other points are rigidly attended to. A slight tremor or shaking of the water is detrimental to a perfect pattern. I have noticed that even a person coughing near the oil-film deranges its conformation.

"Those who have watched these exquisite shapes have often wished to secure them on paper as a kind of photograph,—to have them brought before the eye palpable and fixed, to be seen at once a reality, a permanent image. Many have tried to do so. For long I had attempted to do the same. In many things apparently difficult, yet really simple, we see only that which appears to be insurmountable. It is in their very simplicity, however, that we fail to grasp the solution of the problem. The oil patterns uninjured can as readily be transferred from the surface of water, and permanently fixed to be placed in our albums, as we can pour water from one vessel to another. No matter what colours we desire, we can obtain them of any hue we please. They rival the most beautiful photographs. The faintest tracery is brought out with the most perfect fidelity. Two well-known photographers of this city, to whom I showed them this week, declared they were excellent photographs; and yet not a trace of the chemicals photographers use was employed. The process can be described in three lines: Obtain the oil pattern, note the time, lay a piece of glazed-surface paper on the pattern for an instant, take it off, place on the surface of a plate of ink for a moment, remove and wash off the excess of ink with water, and your pattern is there as it was on the water. You now have an exquisite representation in black, as fine as any photograph. A scarlet is obtained by employing a solution of cochineal or any of the scarlet coal-tar colours. We have them in orange, red, scarlet, black, blue, and other tints. A good result is got by first passing the paper containing the pattern of oil

through ink, and then through cochineal. The principle of the matter is this; the paper absorbs the oil at the several parts, to the exclusion of the water. The ink colours the water parts, but at the same time tints the oil parts very faintly, which gives it the appearance of relievo. Any kind of paper almost will do. Tissue, green, glazed, white, &c., give pretty good results. The paper I employ, which I find to take up the most delicate parts, is what is known as white-surface paper (glazed on one side only). We get it cut in circular pieces of about four inches in diameter. A larger pattern could readily be obtained by using a larger drop of oil and a larger size of paper.

"We have been able to take perfect facsimiles of fern-leaves by coating them with oil, placing them on the glazed paper, pressing them against the paper, obtaining a perfect likeness of the fern, and showing it in relief by drawing the paper through ink, or cochineal, or other colour. In printing with oiled types on the paper and colouring afterwards, we have also been able to get beautiful results. I think that paper-stainers and paperhanging manufacturers might be greatly benefited by paying attention to our method.

"I confidently hope to be able to transfer the patterns even to cloth, to stone, &c.

"Scientific chemists are, of course, only interested in this process so far as a test for the purity of oils. I have made many hundreds of experiments with the process, and in a large number of instances have got results with mixtures of oils differing very materially from those with genuine oils. Many more experiments are needed to confirm this, and in a work on the detection of oils, on which I am at present engaged, having added a large number of reliable tests, this will be very fully gone into."

Since the above was written, Mr. Woodward, Lecturer on Chemistry, Midland Institution, Birmingham, has described in the same valuable scientific journal the following method of

Exhibiting Cohesion Figures to a Lecture Audience.

"Wishing to exhibit the singular figures discovered by Professor Tomlinson and known as cohesion figures, I proposed adopting the method mentioned by Mr. Reynolds in the 'Chemical News' of November 27th; but it occurred to me that an arrangement similar to that used to show waves in water would probably serve the purpose. I therefore tried the following plan, which, though not so successful as the one I shall afterwards describe, is well worth trying:

"A box with a glass bottom was filled with water, and the lime-light placed underneath the box. On throwing a spot of liquid, giving a cohesion figure, on to the water, the figure, more or less definite, was exhibited on a tracing-paper screen placed above the box. Even with a candle underneath the box the figures were visible, but of course not so sharp as when the oxy-hydrogen light was used. This experiment led me to devise the following arrangement, which, with such liquids as I have tried, serves admirably, the figures being projected on to the screen with great clearness:

"In the first place, several troughs are made to hold the water on which to place the creosote, &c. Those I have are made of plate glass. A piece of glass 5 in. square and ⅛ in. thick, has a hole 3 in. diameter cut in it, and this, when laid on a plain piece of glass, forms a circular trough, 3 in. diameter and ⅛ in. deep. An ordinary oxy-hydrogen lantern, from which the nozzle has been removed, is now tilted back so that the light from the lantern is thrown perpen-

dicularly upward, and the trough placed just over the front of the lantern as though it were a lantern-slide. The nozzle of the lantern, fitted to a projecting arm, is then brought over the trough, and an image of the upper surface of the water obtained on the ceiling. On now placing a drop of creosote on the water, an image of it is seen on the ceiling. If it be desired to throw the image on to a vertical screen, a reflecting prism is placed on the nozzle, by which the desired effect is obtained.

"The arrangement will be completely understood by referring to the accompanying figure, in which A is the lantern turned back; C, the chimney; B, the glass trough to hold the water on which the creosote or other liquid is placed; D, nozzle of lantern, supported by the horizontal arm E; F, the reflecting prism; S, screen on which the image is received.

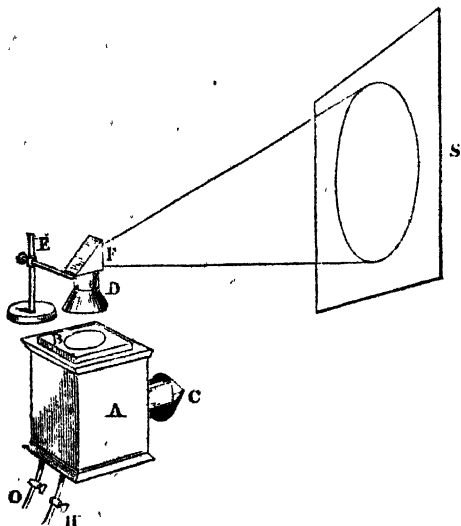


FIG. 463.

"It should be mentioned that it is necessary to remove the usual taper pipe of the nozzle of the lantern, and substitute a shorter one, so that the figures may be properly focussed, and yet room enough left to introduce a pipette between the nozzle and the trough containing the water."

Adhesion (*ad* to, and *hæreo* to stick), the tendency which dissimilar bodies have to adhere or stick together, is expressed by Daniell in Johnsonian grandeur as "heterogeneous adhesion." Water dropped into a polished silver spoon wets it: the fluid adheres to the solid.

Absolutely clean platinum may be quicksilverized (is it right to say wetted?) with mercury: the fluid metal adheres to the solid metal; and this property is taken advantage of in the perfection of barometers, in order to prevent the air adhering to the interior of the barometer, creeping up the sides of the tube, and displacing the mercury.

Negretti and Zambra skilfully prevent the deterioration of their instruments by a method of this kind.

Portland cement, ordinary mortar, compositions used for sticking the parts of broken china together, all act in a similar manner—by adhesion.

There are certain curious modifications of adhesion, which have engaged the most careful attention of learned scientific men. The particular cases that will be mentioned here are those of "Osmose" and "Dialysis."

The word "osmose" is derived from the Greek ὠσμός, impulsion.

Dialysis (δια asunder, λύσις separation) means the separation of certain substances through the intervention of some body, such as parchment paper, through which liquid diffusion may take place.

Many years ago, Dutrochet studied the passage of liquids through porous bodies, and his original instrument, called the endosmometer, has been constructed over and over again by students at medical schools, who wished to verify for themselves the remarkable fact, so suggestive of the explanation of some of the elaborate processes which go on in the economy of the human body.

Dutrochet's instrument consisted virtually of a glass funnel with a long and narrow tube. The mouth of the funnel should be ground flat, and a piece of bladder strained nicely and fixed securely over it. Into the funnel may be poured some alcohol and water, coloured blue with a little indigo; and when this is placed in a shallow vessel or plate containing water, the latter passes through the bladder and gradually diffuses into the alcohol, so that the liquid in the funnel rises, contrary to the law of gravitation, and might overflow if the tube of the funnel were not long enough. This effect is due to the fact that the bladder is more easily wetted by water than by alcohol; the water adheres to the bladder in a greater degree than alcohol, and therefore its lower surface dipping into the water in the plate, is first moistened with water. When the latter has risen by capillary attraction and filled the pores of the membrane, it has reached the upper surface where the alcohol exists; and here, by the adhesion taking place between the two fluids, the plain water and the spirit, they diffuse themselves through each other, and so the process continues, which increases the bulk of the fluid in the funnel; and as the flow is from the outside to the inside, it is called *endosmosis* (ἔνδον inwards, and ὠσμὸς impulse); at the same time a reversal of the process is going on, by which a small quantity of the alcohol passes from the inside to the outside, and this, being exactly contrary to the other, is called *exosmosis*, outward impulse.

Whichever liquid wets the membrane most freely determines the direction of the impulse. Thus, if another funnel be covered with a membrane composed of a thin film of collodion, as the alcohol wets the latter quicker than water, the flow would be more rapid from the inside to the outside, and the former experiment with the bladder would be reversed, the liquid in the funnel falling instead of rising. *

Professor Graham has taken up the subject and examined the phenomena in the most patient and laborious manner, and his experiments show that osmose depends essentially on the chemical action of the liquid, on the particular porous matter or septa used: the corrosion of the septum seems to be a necessary condition of the flow. His experiments were made with saline substances; and, as a proof of the correctness of the explanation, it was found that tanned sole-leather, though a porous substance, showed no osmose or impulse either way, because it is not acted upon by saline solutions.

To set up osmose the chemical action should be different on the two sides of the membrane, and therefore an alkaline solution on one side and an acid one on the other gave some of the best results, the flow of water being chiefly towards the alkaline or basic side. The solution should not be too strong, or the pores may become stopped by the particles of the salt.

* Graham calls the rising of the fluid in the osmometer *positive osmose;* the reverse, *negative osmose.* His elaborate researches are to be found in the "Philosophical Transactions," 1854, p. 177, and "Chemical Society's Journal," Vol. VIII., p. 43.

Osmose no doubt plays a most important function in the economy of life, and promotes that combination of acids and alkalies already alluded to as the probable source of the currents of electricity in the human body.

DIALYSIS.—This department of physical attraction Professor Graham has made peculiarly his own, and, by working out the principle of liquid diffusion, has added another mode of analysis to those previously known.

He divides all soluble substances into two classes, which he terms *crystalloids* and *colloids*.

Bodies capable of crystallization, such as sugar or common salt, would belong to the first, and they are found to have a greater power of diffusive mobility through porous septa.

Substances incapable of crystallization, called colloids from κόλλη, glue, such as many animal substances—albumen, gelatine, or glue; or other bodies—gum, caramel, or starch, do not diffuse themselves easily through septa, and do not assume a crystalline form; they are, moreover, nearly tasteless.

The experiment can be made by stretching an insoluble colloid, such as parchment paper, over a hoop made of gutta-percha, thus forming a shallow tray. If this be floated in a porcelain dish containing distilled water, taking care that the bulk of the latter is nine or ten times that of the contents of the tray, a direct separation of a body, such as arsenious acid, may take place; and supposing a complex mixture of soup, milk, sugar, tea, beer, and arsenious acid is put into the tray, in the course of twenty-four or forty-eight hours arsenic may be detected in the water in the porcelain dish so nearly free from organic matter that the water may be evaporated to a small bulk, and the test of sulphuretted hydrogen applied at once, when the usual characteristic yellow tersulphide may be obtained on the addition of a little hydrochloric acid.

There are many other important separations which may be conducted in a similar manner, and the whole subject is fully discussed in Graham's paper, "Philosophical Transactions," 1861, p. 183.

CHEMICAL ACTION.

This power may refer to many changes: the combination of oxygen with iron taking place slowly in the cold dead iron railings fencing-in our dwelling-houses; the slow, the indirect, but sure attacks of the same element on the dwelling-house of the soul, the human constitution, bring about the inevitable wearing away of the vital battery—the energy that will not for ever respond to the will of the possessor; and thus old age is equivalent to rust, and the ordinary functions of the body that support life come to an end by what is spoken of in connection with dead matter as "reasonable wear and tear." The first entry of air to the lungs of the new-born infant is proclaimed with a cry that may be repeated in another tone as the last gasp of air passes spasmodically from the lips of the departing aged.

Carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorus, and certain earthy and saline matters individually have characteristic properties, and all of these, with the mystery of vital force, contribute to build up the human body. How natural, then, to define "chemical action" to be that change which takes place when one or more substances unite and form another or other bodies perfectly different from those that were engaged in forming it or them

It is chemical action that maintains the greatest of all results—vitality—whether observed in the animal or vegetable kingdom.

Mercury is a brilliant opaque fluid metal: it is sometimes called *quick*silver, because it is difficult to catch. Chlorine is a green gas, very potent and aggressive, and these qualities render it hurtful to the lungs, and, if inhaled, it may excite a cough of a violent description. All these physical properties change when the two unite to form a white, inodorous, insipid substance, insoluble in water—a useful medicine, and commonly called calomel; and their properties change again if more chlorine is united to the mercury, when the resulting salt is found to be soluble in water, and possesses an acrid, nauseous taste that lingers long in the mouth, and is a most violent poison. It is no longer called calomel, but corrosive sublimate; *i.e.*, these are only the vulgar names: strictly speaking, science calls the former mercurious chloride, Hg_2Cl_2, and the latter mercuric chloride, $HgCl_2$.

Chemical action or attraction is, therefore, a subtle power possessing wondrously energetic qualities capable of operating on the minutest particles of matter, at distances that the most refined means cannot measure.

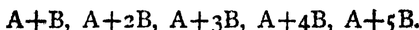
There are laws that rule chemical attraction, as with the other forces, such as electricity, magnetism, &c.

I. *Definite Proportions*, viz., all elements uniting with other elements, combine in certain fixed and invariable proportions, as shown in the table, page 542. The composition of pure water cannot vary: it may be the product of a thousand different changes, but its constituents are fixed to certain proportions,—the weight of the oxygen is always eight times that of the hydrogen.

II. *Multiple Proportions.*—When one body enters into combination with another in different proportions, the numbers indicating the greater proportion are simple multiples of that denoting the smaller proportion.

1. Nitrous oxide	contains	28	parts nitrogen	to 16	of oxygen.
2. Nitric oxide	„	28	„	32	„
3. Nitric trioxide	„	28	„	48	„
4. Nitric tetroxide	„	28	„	64	„
5. Nitric pentoxide	„	28	„	80	„

We may paraphrase the above, and put it thus:



$$A+B,\ A+2B,\ A+3B,\ A+4B,\ A+5B.$$

III. *Equivalent Proportions* result from Law I., and every element displacing another does so in fixed numerical proportions. Knowing the combining weight of mercury, and supposing it to be united with an atom of iodine, it is easy to see, by looking at the table of atomic weights (page 542), what proportion of chlorine would be required to replace one atom of iodine, or how much calcium would be required to replace magnesium if the former were separated from its atomic or combining proportion of sulphuric acid.

IV. Gaseous or aëriform bodies combine in proportions which can be ascertained by exact volumes having a very simple relation to each other.

The ratios may be 1 volume of A to 1 of B, *i.e.*, the gases may unite in equal volumes; or 1 of A to 2 of B; or 1 of A to 3 of B; or sometimes 2 of A to 3 of B.

In the combination of any two gases by volume, this simple proportion is usually observed.

An atomic weight of any particular substance, when converted into the gaseous state at the same temperature and pressure, always yields the same volume.

			Litres.
1 gramme	of hydrogen	at 32° F. and 29·92 in. barometer, *i.e.*, 0° C. and 760 millimètres	=11·19
16 „	oxygen	„ „ „	=11·19
35·5 „	chlorine	„ „ „	=11·19

In the above it will be seen that equal volumes give a variety of weights, 11·19 litres of hydrogen weighing only 1 gramme, and 11·19 litres of chlorine weighing 35·5 grammes. If this arrangement of volumes and weights is reversed, and equal weights are taken of the above-named elements, it is evident that the volumes will differ. So that the difference between combinations by weight and volume must always be remembered in chemical combinations.

	Volumes.
2 gases in equal volumes, represented by two squares, may unite and form	2 ☐☐
3 volumes may be condensed into	2 ☐☐
3 „ „ „	1 ☐
2 „ „ „	1 ☐

The like reasoning applies to compound gases and vapours, which unite in the same simple ratio of volumes with reference to their atomic weights.

It does not seem to be possible to create a large volume, or increase the bulk, of any given volumes of gases that combine with each other. There is thus a constant relation between the atomic weights and volumes of bodies in the gaseous or vaporous state.

NOMENCLATURE.

Before chemistry existed as a science, substances received their names from their real or supposed properties, or from some circumstance connected with their production. Thus phosphorus is derived from two Greek words φως and φερειν (to bear light). The name ammonia is said to be derived from its being produced in quantity by the decomposition of animal matter around the temple of Jupiter Ammon. Potash also received its name from the ancient means of procuring it. This was effected by burning wood in open iron "pots:" the ashes were hence called "pot-ashes."

Some substances were named after the stars and planets, as lunar caustic, *i.e.*, nitrate of silver; mercury, quicksilver. Thus we see the names of most substances were given in an unsystematic manner.

To the elements recently discovered some attempt has been made to give names with like terminations to those elements which resemble one another. Thus three elements ending in *on*, and resembling each other in properties in some respects, are carbon, boron, and silicon.

Chlorine, bromine, iodine, and fluorine form another group resembling one another, and all terminating in *ine*.

The termination *um* is indicative of a metal, as sodium and potassium; and if the Latin names be used, all the metals will be found to end in *um*, as ferrum (iron), plumbum (lead), argentum (silver), &c. With the exception of selenium, no non-metal terminates in *um*.

It is the object of chemical nomenclature not only to name substances, but also through their names to give the knowledge of the elements of which they are composed, and, as far as possible, their proportion.

Speaking of classification and nomenclature, Dr. Hofmann, in the preface to his "Modern Chemistry," says: "The domain of chemical philosophy has, for many years past, rather resembled a tumultuous battle-plain than a field bestowed by Nature for peaceful cultivation by mankind." And a learned critic in the "Athenæum," alluding to that passage, remarks: "But there are many thoughtful observers who, looking upon that cultivated domain, are disposed to believe that the flowers are likely to be choked by weeds, in the shape of an endless number of hypothetical radicals, most complex formulæ, and an unpronounceable nomenclature. On the first introduction of the new chemical philosophy, Herschel explained his objections to the alteration of the term muriatic acid into hydrochloric acid. The evils which he then foresaw have been more than realized, and the literature of chemistry is now deformed with such names as platino-cyanide of diplatosammonium, cymyl-dithionite of sodium, bromide of triammo-dicu-pro-diammonium, and formulæ extending across an octavo page; so that a treatise of chemistry has very much the appearance of a book written in an unknown language. 'It is not necessary to the progress of this science,' write two eminent modern chemists, 'that its language should change with the opinions of every new theorist. . . . They have apparently been engaged in working out an idea, and seeking for some

Utopian standard of perfection in a new system of notation; but in endeavouring to settle contested points on a firmer basis, they have incurred the risk of unsettling everything.'"

When two elements unite together they form what is called a binary compound, such as oxide of zinc, or zincic oxide. This name gives at once the knowledge that the compound consists of two elements, zinc and oxygen, one equivalent of each being in the compound.

The non-metallic elements combined with each other, or with the metals, form the principal binary compounds.

In the following table* is shown the nomenclature of binary compounds: the symbols of the compounds are in the fifth column.

The Compounds of	Are termed	For example:	or	Or in Symbols,
Oxygen...	Oxides	Zincic oxide	Oxide of zinc	ZnO
Chlorine	Chlorides ...	Argentic chloride	Chloride of silver	$AgCl$
Bromine	Bromides ...	Sodic bromide	Bromide of sodium	$NaBr$
Iodine ...	Iodides	Potassic iodide	Iodide of potassium	KI
Fluorine	Fluorides ...	Potassic fluoride	Fluoride of potassium	KF
Nitrogen	Nitrides	Boric nitride	Nitride of boron	BN
Carbon ...	Carbides or Carburets	Nitric carbide (cyanogen)	Carbide of nitrogen	CN
Sulphur..	Sulphides or Sulphurets	Cupric sulphide	Sulphide of copper	CuS
		Plumbic do.	Sulphuret of lead	PbS
Selenium	Selenides or Seleniurets	Mercuric selenide	Selenide of mercury	$HgSe$
		Cadmic do.	Seleniuret of cadmium	$CdSe$
Phosphorus	Phosphides or Phosphurets	Calcic phosphide	Phosphuret of calcium	CaP

In employing symbols, the symbol of the basylous or electro-positive element is generally placed first.

When the same elements unite in various proportions, Latin or Greek numerals are used as prefixes to distinguish between the different compounds of the same elements. Thus the first oxide of ruthmium is called the protoxide, RuO; the second oxide is called the deutoxide, RuO_2; the third is named the trioxide, RuO_3.

The name *binoxide* is applied to the oxide that contains twice as much oxygen as the protoxide.

* From Miller's "Elements of Chemistry," Part II.

The prefix *sesqui* is given to compounds which contain two elements in the proportion of 3 to 2, or 1½ to 1, as sesquioxide of ruthmium, Ru_2O_3. The prefix *per* signifies the highest combinations, as perchloride of mercury.

Many oxides form, when united with the elements of water, acids.

Some bodies have two or more oxides, which form, with the elements of water, acids; and in order to distinguish between them a certain nomenclature is made use of. Thus the name of the acid containing the largest proportion of oxygen terminates in *ic*, as sulphuric acid, H_2SO_4, and that with the less amount ends in *ous*, as sulphurous acid, H_2SO_3.

An acid has sometimes been discovered containing a larger proportion of oxygen than the one to which the termination *ic* had been given. Then the prefix *per* has been used to denote this, as chloric acid $HClO_3$, and perchloric acid, $HClO_4$.

An acid containing less oxygen than the one ending in *ous* has the prefix *hypo*, as chlorous acid, $HClO_2$, hypochlorous acid, HClO.

Besides these acids which contain oxygen, there are others which contain no oxygen; for instance, hydrogen and chlorine combine to form hydrochloric acid, HCl; also hydrogen and iodine form hydriodic acid, HI.

In the naming of the oxysalts—the union of an oxyacid with a base—the name of the salt containing the acid with the largest proportion of oxygen terminates in *ate*, as the compound of sulphuric acid and soda is called disodic sulphate, or sulphate of sodium, Na_2SO_4; whilst the salt of the acid containing less oxygen, and terminating in *ous*, ends in *ite*, as the compound of sulphurous acid and soda is named disodic sulphite, or sulphite of sodium, Na_2SO_3.

When a metal forms more than one basic oxide, *i.e.*, more than one oxide capable of forming salts by the action of acids, the name of the metal in the oxide containing the smaller proportion of oxygen ends in *ous;* and in the oxide containing the larger amount of oxygen it terminates in *ic*, as in the case of iron.

The protoxide is called ferrous oxide, FeO, and the salts of this oxide ferrous salts, as ferrous sulphate, $FeSO_4$ ($+7$ H_2O, water of crystallization).

The sesqui oxide is termed ferric oxide, Fe_2O_3, and its salts ferric salts, as ferric sulphate, Fe_23SO_4.

Most chemists of note now look upon acids as salts of hydrogen, the latter representing the metallic part. And when these hydrogen salts act upon other metals, they look upon the reaction as a replacement of hydrogen. There is no doubt that this system is quite consistent, and much more in accordance with observed facts, than the older ideas, which are daily losing ground.

When a molecule of an acid contains one atom of hydrogen capable of being replaced by one atom of a monad metal, it is called a monobasic acid, such as nitric acid, HNO_3, the hydrogen of which can be replaced by one atom of the monad metal potassium. If it contain two atoms of replaceable hydrogen, it is called dibasic, such as sulphuric acid, H_2SO_4, the two atoms of hydrogen which it contains being replaceable by two atoms of a monad metal like potassium, or one atom of a dyad metal such as copper. Those bodies which contain more than one atom of replaceable hydrogen are called polybasic.

The terms monad, dyad, triad, tetrad, pentad, and hexad are used to denote the equivalents of the different elementary bodies in compounds as compared with hydrogen.

If we compare the equivalents of the elements in compounds with hydrogen, we find that they differ very much in value. Thus;

The monad	potassium	is equivalent to	1 atom of	hydrogen	in a compound.
The dyad	zinc	"	2 atoms of	"	"
The triad	bismuth	"	3	"	"
The tetrad	platinum	"	4	"	"
The pentad	nitrogen *	"	5	"	"
The hexad	manganese	"	6	"	"

TABLE OF THE SYMBOLS, AND NEW AND OLD COMBINING OR ATOMIC WEIGHTS OF THE ELEMENTS.

Names of Elements.	Symbol	New At. Wt.	Old At. Wt.	Names of Elements.	New At. Wt.	Old At. Wt
Aluminium ...	Al	27·4	13·7	Molybdenum..		48·0
Antimony......	Sb	122·0	—	Nickel		29·5
Arsenic.........	As	75·0	—	Niobium ...		
Barium	Ba	137·0	68·5	Nitrogen		
Bismuth	Bi	210·0	—	Norium.........		
Boron	B	10·9	—	Osmium	199·0	
Bromine	Br	80·0	—	Oxygen.........	16·0	
Cadmium	Cd	112·0	56·0	Palladium......	106·5	
Cæsium	Cs	133·0	—	Phosphorus ...	31·0	
Calcium	Ca	40·0	20·0	Platinum	197·2	
Carbon	C	12·0	6·0	Potassium ...	39·1	
Cerium	Ce	92·0	46·0	Rhodium	104·2	
Chlorine	Cl	35·5	—	Rubidium......	85·3	
Chromium ...	Cr	52·5	26·25	Ruthmium ...	104·2	
Cobalt	Co	59·0	29·5	Selenium	79·5	
Copper	Cu	63·4	31·7	Silicon	28·0	
Didymium ...	D	96·0	48·0	Silver	108·0	
Erbium.........	E	114·6	—	Sodium.........	23·0	
Fluorine	F	19·0	—	Strontium......	87·5	43·8
Glucinum	Gl	9·4	4·7	Sulphur.........	32·0	16·0
Gold	Au	196·6		Tantalum......	137·6	68·8
Hydrogen ...	H	1·0		Tellurium......	129·0	64·5
Indium	In	74·0		Thallium	204·0	
Iodine	I	127·0		Thorium	115·7	
Iridium.........	Ir	197·2	98·6	Tin	118·0	
Iron	Fe	56·0	28·0	Titanium	50·0	
Lanthamium..	La	92·0	—	Tungsten	184·0	
Lead	Pb	207·0	103·5	Uranium	120·0	
Lithium	Li	7·0	—	Vanadium ...	137·0	
Magnesium ...	Mg	24·3	12·15	Yttrium.........	61·7	
Manganese	Mn	55·0	27·5	Zinc	65·0	32·5
Mercury .	Hg	200·0	100·0	Zirconium......	89·5	44·75

The above is a list of the elements at present known to chemists, with

* Usually triad, sometimes pentad.

their symbols, and their new and old combining or atomic weights. As it would be inconvenient, in expressing chemical reactions in writing, to write the whole name of an element, the first or first two letters of the name are used as symbols to denote any particular element; thus O stands for oxygen, H for hydrogen, Co for cobalt. In the case of some metals, the first and prominent letters of the Latin name are used as symbols, as Ag for silver (argentum), Pb for lead (plumbum). The first two letters of the name of an element are used as its symbols when there is another element beginning with the same letter. Thus C is used as the symbol of carbon, and Cl is used for chlorine, in order to distinguish between the two. The symbol of an element when used by itself not only stands for that element, but also for a certain proportion thereof by weight, called its atomic weight; such proportion being the smallest proportion by weight in which such element combines with, or is eliminated from, a chemical compound, hydrogen being taken as unity.

Thus C does not stand merely for carbon, but also for exactly 12 parts by weight of carbon, or O stands for 16 parts of oxygen.

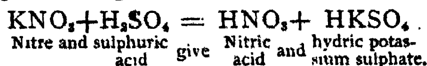
The small figure placed to the right hand of the symbol of an element signifies the number of atoms of that element. Thus C_4 means 4 atoms, or 4×12 parts of carbon; O_2 means 2 atoms, or 2×16 parts of oxygen.

The symbols of compounds are made by placing the symbols of the elements forming the compounds side by side, as

Water	H_2O
Sulphuric acid	H_2SO_4
Ammonia	H_3N

When more than one molecule of a compound has to be denoted, a large figure is placed to the left hand of the formula of the compound, and all the symbols in the formula are multiplied by the large figure which stands before it; thus $2H_2O$ means two molecules of water.

Chemical reactions are expressed by equations. The symbols of the elements before the change are placed on one side of the equation, and the symbols representing the change effected on the other, thus:



$$KNO_3 + H_2SO_4 = HNO_3 + HKSO_4$$

Nitre and sulphuric acid give Nitric acid and hydric potassium sulphate.

It is necessary to distinguish clearly between the terms *atom* and *molecule*. An atom means something which cannot be further subdivided. And thus, in the table of elements (p. 542) O stands for one atom of oxygen, H for one atom of hydrogen. A molecule may contain more than one atom, as, for instance, H_2: this would be called a molecule containing two atoms of hydrogen; H_2O would be a molecule of water; and H_2O_2 a molecule of peroxide of hydrogen or hydric peroxide, or oxygenated water. These expressions are most important, and prevent the confusion of the term "atomic" with that of "equivalent," because they are quite different from each other. A *molecule* is very properly defined by Roscoe to be "the group of atoms forming the smallest portion of a chemical substance, either simple or compound, which can exist in the free state." And he gives a good illustration of the difference between *atomic* and *molecular* formulæ in the following: $H + Cl = HCl$ is the atomic expression, whilst $H_2 + Cl_2 = 2HCl$ is the molecular expression for the same reaction.

ELEMENTS WHICH ARE NOT METALLIC.

OXYGEN.

Symbol, O. Atomic weight, 16.

In the month of August, 1774, Dr. Priestly discovered this important element, and Mr. George Rodwell has very properly insisted, in a learned paper in the "Chemical News," that it was not discovered by Swedenborg half a century before Priestley, and that there is not a particle of reliable evidence in support of this statement. "We are quite unable," says Mr. Rodwell, "to comprehend by what contortion of the meaning of the principal passage quoted, Swedenborg can be supposed to allude to oxygen. 'Air,' he writes, 'consists superficially of fifth finites, and within it are enclosed the first and second elementaries.' And again: 'The fifth finites have entered into the surface of the aërial particle, and the first and second elementaries into the internal space.' There is no possible reason for assuming that by the meaningless term 'fifth finites' oxygen gas is alluded to; and if there were any evidence at first sight, it would be speedily nullified by the fact that Swedenborg afterwards speaks of *crystals* of this matter. It is useless to pursue the subject further: the only evidence in support of the supposition is so utterly shallow that it is not worthy of criticism, for it carries with it its own refutation."

Dr. Priestley obtained the first oxygen produced from "red precipitate," (the red oxide of mercury) by heating it at a temperature of 752° F.—expressed in symbols, HgO—yield Hg+O.

Lavoisier, in his "Elements of Chemistry," says this "species of air" was discovered about the same time by Dr. Priestley, Mr. Scheele, and "*myself*."

In a pamphlet published in 1800 by Priestley, after his return to America, he says, "Having made the discovery some time before I was in Paris in the year 1774, *I mentioned it* at the table of M. Lavoisier, when most of the philosophical people in the city were present, saying it was a kind of air in which a candle burned much better than in common air, but I had not then given it any name. At this all the company, and M. and Madame Lavoisier *as much as any*, expressed great surprise. I told them I had gotten it from *precipitate per se*, also from *red lead*. Speaking French very imperfectly, and being little acquainted with the terms of chemistry, I said *plomb rouge*, which was not understood until M. Macquer said I must mean *minium*. Mr. Scheele's discovery was certainly independent of mine, though, I believe, not made *quite so early*."

Scheele obtained oxygen from one of the minerals of his own country as he happened to be investigating the nature of the ores of manganese.

Lavoisier, with the quickness of wit belonging to his countrymen, does not appear to have been slow in verifying Priestley's experiment, which was *analytical*. Great credit is due to Lavoisier for reversing Priestley's experiment, and making it *synthetical*: by subjecting a given quantity of air to the action of boiling quicksilver, he made that which Priestley decomposed—viz., red precipitate.

The latter called oxygen Dephlogisticated Air. Lavoisier gave the element a name which has remained, like an official registry of a baptismal name, to the present time. He called it Oxygen (οξυς acid, γεννάω to produce), while others styled it Empyreal, or Vital Air.

One method of preparing oxygen gas has already been mentioned, viz., that of heating the red oxide of mercury. This may be easily done in a test-tube, and the escape of the oxygen gas is soon rendered evident by a splinter of wood inserted, with the end carbonized and just red hot or glowing, which immediately bursts into flame with a sort of explosion, and then burns with great brilliancy.

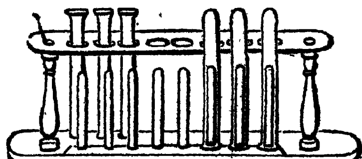


FIG. 464.—*Test-tubes and Rack.*



FIG. 465.—*A Quicksilver Bottle of wrought iron, used for heating the black Oxide of Manganese.*

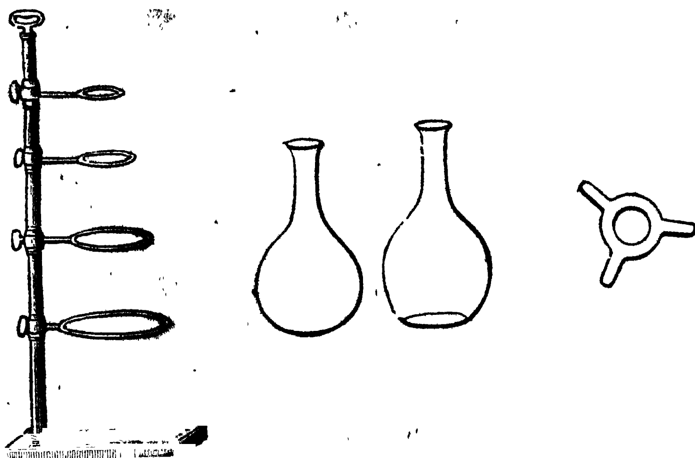
With respect to the chemical apparatus that may be described in this section, the reader is recommended to go to Mr. How, Foster Lane, Cheapside, where every kind of chemical apparatus may be obtained.

At the Polytechnic, where oxygen is used in very large quantities for the oxy-hydrogen light, it is made by heating the black oxide of manganese, MnO_2, in wrought-iron bottles.

Three equivalents of MnO_2 yield the red oxide Mn_3O_4 and two equivalents of oxygen gas. The plug is taken out of the iron bottle, and an iron pipe screwed into it: this is connected with a large flexible tube, and, first bubbling through a simple washing apparatus, the gas passes direct to a large copper gasometer. Good black oxide of manganese is worth about £9 a ton, and should yield one-ninth of its weight of oxygen gas. It very rarely happens that the mineral affords more than half that quantity. At the Polytechnic an average of eight tons are used during the year; one-sixteenth of this, viz., ten cwts., will represent the weight of oxygen used in that establishment.

On the small or the large scale, where cost is of little consequence, oxygen is readily procured by heating potassic chlorate (chlorate of potash), not alone, because the heat softens the glass vessel, but mixed with one-third or one-

fourth of black oxide of manganese. The oxygen escapes at a temperature of 450° or 500° F., and the black oxide of manganese undergoes no decomposition. One ounce of the chlorate will yield about two gallons of oxygen— $2KClO_3 = 2KCl + 3O_2$.



FIGS. 466, 467, 468.—*A Ring Stand, with reducing Porcelain Ring, to support, if necessary, the Flask.*

The flask containing the chlorate mixture is fitted with a cork and bent tube, and heated by a spirit-lamp, or by any of the convenient gas-burners which consume mixed air and coal-gas.

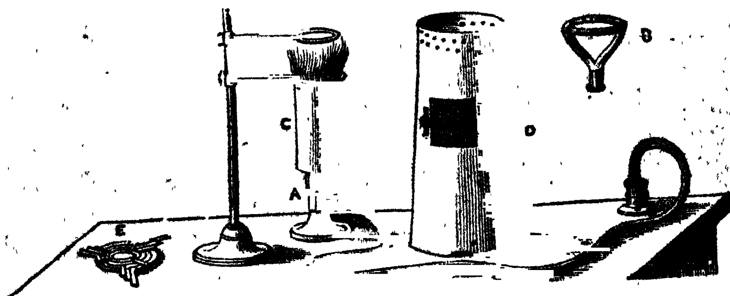


FIG. 469.—*Various Gas-burners used for heating purposes.*

A, mixed gas and air burner, with wire gauze at the top of the chimney, C; sheet-iron case, D, for protecting a gas or spirit-flame from currents of air and economizing heat; B, a ring perforated with holes for burning gas; E, rings of wire for reducing the size of the large rings of the ring stand, in order to support smaller vessels.

The oxygen gas may be collected in jars placed upon the shelf of the very convenient tank of water called a Pneumatic Trough.

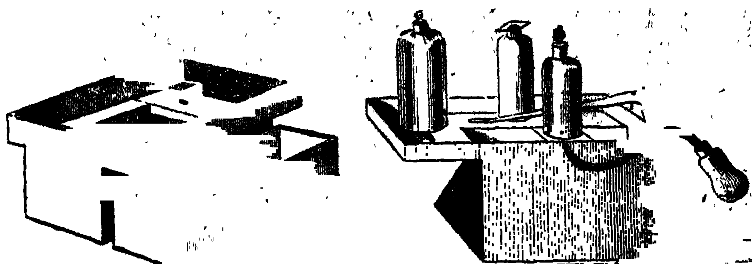


FIG. 470.—*A Pneumatic Trough.* FIG. 471.—*Pneumatic Trough in use.*

In the above, Fig. 470, another box is provided, to receive any overflow and to prevent the slopping of water on the table where the experiments are conducted. The ordinary pneumatic trough, with the gas-jars on the shelf, and the flask and tube or retort containing the substance yielding gas, is shown in Fig. 471.

When large quantities of oxygen are required for the oxy-hydrogen lantern, the gas is conveniently and quickly made from the chlorate mixture by placing it in a thin sheet-iron vessel made in the form of a cone: the latter can be placed over a larger ring of burning gas or on an open fire; and by taking the precaution to pass the oxygen first through a wash-bottle containing a little slaked lime and water, a great deal of the chlorine produced from the decomposition of the potassic chlorate is absorbed. If the chlorine be not

FIGS. 472, 473.—*Highley's arrangement for making and washing the Oxygen Gas.*

removed with lime, or, better still, with potash, it soon acts upon the brass taps fixed into the caoutchouc bags; and when—perhaps at a critical moment—a good light is wanted, the tap is stopped up, and the microscopic slide or the magic lantern picture is badly lighted.

In the article on the dissolving view apparatus Mr. Samuel Highley, of 10

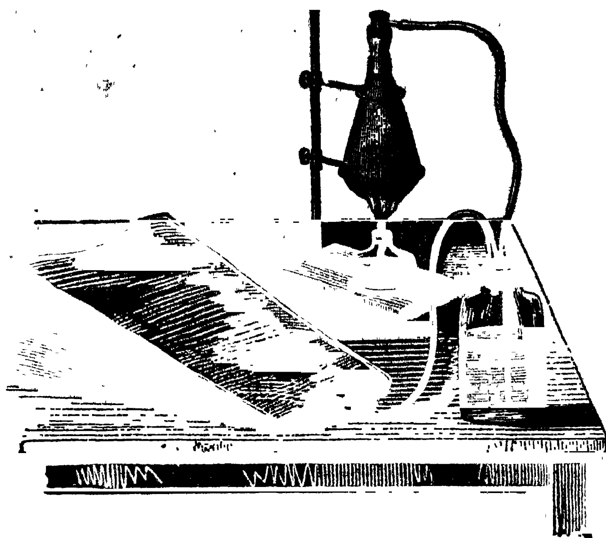


FIG. 474.—*Gas Generator, Spirit-lamp, Ring Stand, Wash Bottle, and Gas-bag.*

Great Portland Street, has been recommended for all apparatus of that kind; and another simple arrangement of a thin sheet-iron or copper bottle containing the chlorate mixture, attached by flexible tubes to a simple washing apparatus made with a corked bottle, into which the pipe from the generator dips, with a delivery-pipe passing to an india-rubber bag, is shown at Fig. 474.

There are many other ways in which oxygen can be made, all detailed in works devoted to chemistry, such as Dr. Miller's "Elements of Chemistry," or Abel and Bloxam's "Handbook."

THE PROPERTIES OF OXYGEN.

The specific gravity of this gas is 1·10563: it is perfectly tasteless, odourless, and colourless, and has never been reduced by extreme cold or great pressure into the liquid or solid condition; oxygen is therefore said to be a permanent gas. With the exception of fluorine, oxygen unites with every other known element.

Charcoal, sulphur, phosphorus, many of the metals, such as iron, zinc, potassium, and sodium, burn in this gas with great brilliancy, forming acids, oxides, and alkalies.

The act of dissolving a metal in nitric acid is called oxidation, the acid yielding oxygen to the metal, which oxide afterwards unites with another portion of the acid.

Liquid red hot nitre acts as a powerful oxidizer, in which the hardest form of carbon, viz., the diamond, is readily oxidized and dissolved, by forming carbonic anhydride, which unites with the dipotassic oxide or potash—K_2O.

One hundred cubic inches of oxygen, at 60° and 30 in. barometer, weigh 34·203 grains. Water dissolves a small volume of oxygen gas.

100 volumes of water dissolve 4·11 volumes of oxygen at 32° F.
100 „ „ 2·99 „ „ 59° „

Remarks.

It has been ascertained that oxygen possesses weak but decidedly magnetic properties, like those of iron, liable to diminution or increase by raising and lowering the temperature. Oxygen is a dyad, as in H_2O, in common with sulphur, selenium, and tellurium.

The atomic weight of oxygen is now taken as 16 instead of 8, so that water is represented by the formula $H_2O = 18$ instead of 9.

Oxygen represents nearly one-fifth of the bulk of the atmosphere, the component parts of which will be considered hereafter.

Every nine pounds of water contain eight of oxygen.

Nearly half the weight of dry sand and clay consists of oxygen.

The vital functions cannot be maintained without oxygen, and by a species of slow combustion, or oxidation of the blood through the ramifications of the lung process, heat is slowly produced; and that a new product is formed is shown by the quantity of carbonic anhydride expired with the breath, and the change of the dusky purple or dark blood to bright crimson.

There is no gaseous body more serviceable and important to man, or any element which has helped to increase the industrial wealth of this country so much as oxygen.

The various compounds it forms, such as oxides, acids, basic oxides, alkalies, and saline oxides, will be referred to in other places.

The tests for oxygen are combustion with hydrogen and formation of water.

The change of colour when a solution of pyrogallic acid in potash is shaken with oxygen.—The solution of potash alone will not dissolve oxygen, but the pyrogallic acid determines the rapid absorption of this gas and turns a dark brown colour.

A mixture of colourless nitric oxide gas, NO, with oxygen, forms red fumes, which are readily soluble in water.

Ozone.

Although oxygen has never been changed from the gaseous state to a liquid or solid condition, it seems to be capable of assuming a peculiar condensed form called Ozone,—a word taken from the Greek ὄζω, to give out an odour.

MM. de Babo, Claus, and Soret all maintain that ozone is oxygen denser than common oxygen gas. The latter philosopher especially declared that ozone as a molecule consisted of three atoms of oxygen, and he therefore called it *binoxide of oxygen.* M. Soret, in continuation of his researches on the density of ozone, and employing the absorptive powers of essences of turpentine and cinnamon, has come to the conclusion that the density of ozone is $1\frac{1}{2}$ times that of oxygen, and gives as the formula for ozone Θ_3. Other learned chemists appear to concur in this opinion.

Ozone is produced in various ways.

1. By passing a series of electrical discharges—silent ones—through dry oxygen gas: the latter diminishes in bulk to the extent of one-twelfth, showing condensation; and if subsequently heated to a temperature of 550° F., re-

covers its former bulk and loses its peculiar ozone qualities. The reason the electrical discharge should be a silent one is because the electrical spark produces too much heat, which destroys a considerable portion of the ozone, and thus prevents any considerable accumulation. At p. 388 Siemen's apparatus is described (an induction apparatus), by which large quantities of oxygen may be converted into ozone.

2. This peculiar condition of oxygen is obtained by acting either on potassium permanganate ($KMnO_4$) or upon baric dioxide (BaO_2) with strong sulphuric acid.

3. A stick of phosphorus scraped clean under water, and then exposed in a bottle containing moist air, produces ozone.

4. When water is decomposed in the apparatus called a voltameter, the mixed gases give the peculiar odour and are found to contain a certain quantity of ozone.

The best tests for this condensed form of oxygen are potassium iodide, and starch paste painted with a brush on paper, or paper dipped in a solution of sulphate of manganese, $MnSO_4+5H_2O$. The first turns blue from the liberation of iodine and the formation of a blue compound of starch and iodine; and the second indicates the presence of ozone by the formation of the brown hydrated peroxide of manganese.

Schonbœin, who first directed attention to this allotropic condition of oxygen, directs the test-paper to be made of a fixed strength, by dissolving one part of pure potassic iodide in 200 parts of distilled water, which is then to be thickened by heating it with 10 parts of starch. This solution is to be applied to bibulous paper, which, when dry, should be kept in a stoppered bottle covered with tin foil, in order to exclude the light.

It is known that sea-air contains ozone, whilst the same air, having passed over or through a town, is supposed to be deprived in a great degree of this agent, which is considered to have purifying and health-giving powers. The absence of ozone from the air is said to be prejudicial to health, and during the prevalence of cholera it was thought to be due in some degree to the absence of this condition of oxygen.

Dr. Daubeney found, in the three winter months commencing with January, at Torquay, that the south-west and westerly winds were most fully charged with ozone, whilst the north winds showed the least. On the contrary, at Oxford during the summer months of the same year, the easterly winds were most charged with ozone, and the north-westerly the least. These indications clearly pointed to the influence of the sea in augmenting the amount of ozone at Torquay, whilst the more central inland position of Oxford caused the difference between the maximum and minimum indications to be much less apparent than at the sea-side. Daubeney also found that plants growing in the sunshine liberate a body that affects the starch test like ozone, and hence inferred that this remarkable property of plants might have something to do with the maintenance of the healthiness and purity of the air.

Ozone possesses most energetic qualities. It sets free iodine from its combination with the metals. Black sulphide of lead or plumbic sulphide (PbO) is attacked by ozone; the black stain disappears, and both the sulphur and the lead oxidize, the white sulphate of lead ($PbSO_4$) being produced. Ozone is a powerful bleaching agent: it irritates the lungs if inhaled in any quantity; and this is not surprising when it is remembered that both cork and caoutchouc are not proof against its oxidizing power. Silver, which resists common

oxygen, and is so often used in chemical processes for this reason, is converted into peroxide when exposed to the action of ozone, provided that the presence of moisture is secured.

Ozone is now introduced into certain chemical processes, and is likely to take a very prominent place as one of the oxidizers, the wealth-producers in refining sugar, bleaching calico, &c.

NITROGEN.

Symbol, N. Atomic weight, 14.

Nitrogen is described in an old work as "a simple oxidable body, by some chemists called *azot*, from its property of destroying life. This name appears improper, since several other gases have the same effect on animals." It was discovered by Dr. Rutherford in the year 1772, and was called Nitrogen from νιτρον nitre, and γενναω to generate.

It would be difficult to speak of nitrogen without alluding to the important part it takes in the composition of the atmosphere. Rodwell says, from the continued observation that the cessation of breathing was the cessation of life, the belief became prevalent that the soul passed from the body with the last expiration of air; hence the expressions, "Efflare animam," "Exhalare animam," "Expiram animam." Again, πνευμα, *spiritus*, *anima*, have each the triple meaning of *soul*, *breath*, *wind*. There is also a Hebrew word having the same meaning as the Greek *pneuma*, viz., soul, breath, wind. The most convenient mode of preparing nitrogen is by removing the oxygen from atmospheric air, and when this is done it is found that it constitutes four-fifths of any given bulk. A variety of processes may be employed for this purpose, but the simplest plan is to place some dry phosphorus in a German porcelain cup, and having properly supported it on the shelf of the pneumatic trough, a long unstoppered gas-jar graduated into five equal parts is placed over the whole; a heated wire is now inserted, and directly it touches the phosphorus, the latter ignites, and the stopper of the jar is quickly inserted. At first expansion occurs, and therefore the depth of water should be adjusted beforehand, so as to allow the heated air to increase in volume without bubbling out and escaping from the bottom of the jar.

If the above manipulations are skilfully performed, very little air is lost: the phosphorus burns, producing the white fumes of phosphoric pentoxide, which gradually subside, and are dissolved, by the water. The residual gas, when cold, is found to be equal to four-fifths of the original bulk, one-fifth—viz., the oxygen—being removed by combining with the phosphorus.

The same result is more accurately obtained by thrusting up into a graduated tube containing atmospheric air a piece of phosphorus supported in a coil of platinum wire: after two or three days the phosphorus may be removed, and the remaining gas is found to be nearly pure nitrogen; and if 100 measures of air be used, 20 will be removed and 80 left.

Another mode of preparing nitrogen is by passing air over finely divided metallic copper at a red heat. The experiment conducted by Dumas and Boussingault was performed by them with great precautions in the exact analysis of air, and they found that 100 parts, by weight, of air from which the aqueous vapour, carbonic anhydride, and ammonium had been removed,

contained 77 parts of nitrogen and 23 parts of oxygen; or, more precisely, taking the average of a number of experiments,—

	Weights.	Volumes.
Nitrogen	76·99	79·19
Oxygen	23·01	20·81
	100·00	100·00

Nitrogen has no colour, taste, or smell. It is lighter than oxygen gas, and slightly lighter than atmospheric air: 100 cubic inches at 60° F., 30 in. bar., weigh 30·119 grains. A lighted taper immersed in this gas is immediately extinguished, no incandescent snuff remaining. It must not, however, be supposed that nitrogen is poisonous: it simply destroys life in the absence of oxygen gas, and cannot be poisonous, or we could not continue to breathe air, which is a mechanical mixture of the two gases always maintained in the same relative volumes by one of those wonderful conservative powers of Nature represented by the vegetable kingdom. Although the two gases differ in weight, they never separate; and by the law of the universal diffusion of gaseous bodies, they have the power of incorporating perfectly with each other; and this property of gases in general, and specially in this case, has, no doubt, the most important bearing on the purity and healthiness of the air. No combination occurs between the oxygen and nitrogen contained in atmospheric air, although it is quite possible to conceive that where ozone is produced in hot climates with certain peculiarities of soil—as in Spain, Egypt, and India—that there the nitrogen is attacked by the condensed oxygen ozone, and nitrates produced.

Professor Graham has shown that the velocity of the diffusion of the various gases is in the inverse ratio of the square roots of their densities; and, as before stated, this principle of diffusion explains why the composition of 100 parts by volume of the air may be taken at an average as follows:

Country air.	Nitrogen	77·95
	Oxygen	20·61
	Carbonic anhydride (carbonic acid) .	·04
	Aqueous vapour	1·40
	Hydric nitrate (nitric acid) . . .	traces
	Ammonia	traces
	Carburetted hydrogen	traces
Town air also	Sulphuretted hydrogen . . } traces.	
	Sulphurous anhydride . . } traces.	100·00

HYDROGEN.

Symbol, H. Atomic weight, 1.

Although this article on Chemistry must necessarily be confined to certain limits, and therefore the various compounds formed by the combination of the different elements cannot all be considered, exceptions to this rule must occasionally be made; and having considered the chemical nature of air, it would be hardly possible to avoid making some remarks on the constitution of water, the more so as this is the chief source from which hydrogen is obtained.

Water is presented to us in nature having different degrees of purity; hence we speak of hard or soft water. The former may contain calcium carbonate and sulphate, magnesium carbonate and sulphate, sodium sulphate and chloride, and many other substances, in considerable quantities, especially if the water flowing into the well be derived chiefly from surface drainage. When the water—such as rain-water—has been collected after several hours' rain, it is almost in a state of purity, containing then only certain gaseous matters in solution: such water is usually called soft, because it is free from the salts already mentioned. If the rain-water be collected after a long drought, it may then contain nitrates and salts of ammonium, and, if near the sea-side, would always contain sodium chloride or common salt.

River-water usually comes under this denomination, because it contains a less proportion of saline matters in solution: it is not, however, so good to drink as spring-water, because it frequently occurs that rivers receive the sewage of large towns, and hence the water contains organic matter in solution, and, should the water be taken whilst this organic matter is undergoing decomposition, very serious consequences may result to the person drinking it. It is now, however, a rule in sanitary matters to endeavour to divert the sewage from our noble rivers when possible, and with the help of proper filters the Thames water is now potable and wholesome.

All rivers flow into the sea, hence sea-water contains a larger quantity of sodium chloride, and many other salts, in solution, likewise organic matter; but, curious to say, it remains in a uniform condition so far as the quantity of saline matter is concerned, and the specific gravity varies little, the mean being 1,027, pure water being 1,000.

When sea-water or any other hard water is placed in a still and boiled, the earthy or saline matters are left behind, and, the steam only being condensed, pure water is obtained.

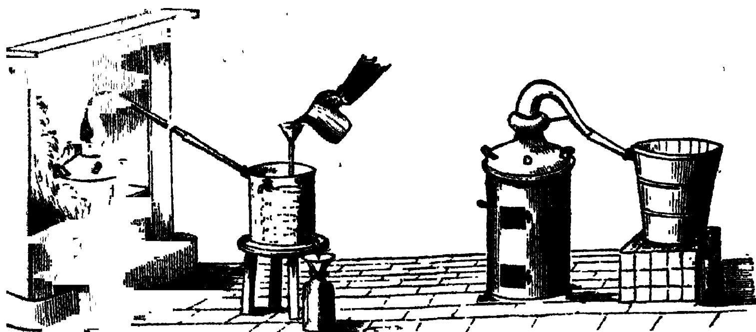
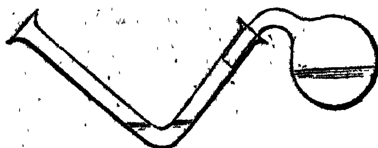


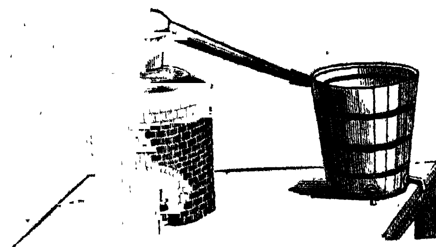
FIG. 475.—*The Still placed on a common fire or fitted to a proper furnace.*
Both the stills have worm tubs or condensers.

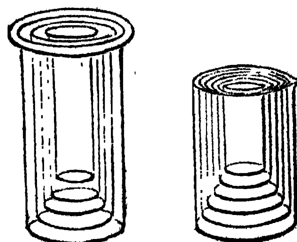
The operation of distilling may be performed on a very small scale by using a little flask fitted into a bent tube, which is placed in a basin containing cold water (Fig. 476). Very convenient little tin or copper stills are made by Mr. How, of Foster Lane, Cheapside: they are heated by a Bunsen burner, and will supply a sufficient quantity of fresh distilled water for any analytical operations con-


FIG. 476.

ducted on a moderate scale, and, with a very little attention and a small consumption of gas, they will readily yield a Winchester quart of distilled water per diem.

Water when absolutely pure has no taste or smell, is free from colour, except when examined in particular thicknesses, and perfectly transparent.


FIG. 477.—*Small Tin or Copper Still, with Worm Tubs, to be heated by Gas.*


FIG. 478.—*Useful Vessels called Beakers, in which Solutions are prepared.*

It is invaluable as a solvent, and no laboratory is complete without a proper supply of it stored in well-stoppered bottles.

Pure water is the standard to which the specific gravities of other liquids and solids are referred.

Under the ordinary pressure of the air, it boils at 212° F. If, however, it be confined in a very strong wrought-iron vessel, such as the apparatus called a Papin's digester, the boiling-point is raised, and, as the steam does not escape, the solvent powers of the water are greatly increased. Water has in this way been raised to the temperature of 419° F., and Muschenbroek stated that he had made water hot enough in a Papin's digester to melt tin.


FIG. 479.
A Papin's Digester with Safety Valve.

The chemical composition of water may be determined analytically or synthetically. In the article on voltaic electricity it has been shown that water, when subjected in a proper manner to a current of electricity, is decomposed into oxygen and hydrogen, and if they are collected in separate tubes, the latter, eliminated at the platinode or negative platinum plate, is found to be double the volume of the oxygen set free at the zincode or positive plate. Thus the composition of water is shown to be in the proportion of two measures of hydrogen with one of oxygen. According to modern views, the atomic constitution of water is represented by the formula H_2O $=18$, instead of, as formerly, $HO=9$.

There are many other modes of decomposing water. If steam is passed over red hot iron borings, the metal unites with the oxygen, and the hydrogen may be collected in the ordinary manner.

When the electric spark from a coil is passed through steam, the latter is decomposed into the two gases.

A small pellet of sodium, wrapped in blotting-paper and thrust under a jar full of water standing on the pneumatic trough, immediately liberates hydrogen gas, the metal taking the oxygen, and forming with the water sodium hydrate, HNaO, which is quickly dissolved. A very small piece should be used, as the decomposition occurs with explosive violence.

The common method of preparing hydrogen is by acting on zinc with dilute sulphuric acid. The probable metallic character of the hydrogen is well illustrated, because it is displaced by the zinc, sulphate of zinc is formed, and the hydrogen escapes in the gaseous state. The change which occurs is explained in the following simple equation:



$$H_2SO_4 + Zn = ZnSO_4 + H_2$$

Hydrogen when absolutely pure is free from colour, taste, or smell. It is the lightest of all known substances, being about fourteen times lighter than atmospheric air, and sixteen times lighter than oxygen gas.

A hundred cubic inches at 60° F. and 30 in. bar. weigh 2·14 grains; consequently the name of balloon is almost synonymous with that of hydrogen, and soap-bubbles inflated with this gas rise with great rapidity.

Hydrogen is combustible and was called by Cavendish "inflammable air." A burning taper is extinguished when introduced into this gas; hence oxygen was called a "supporter," and hydrogen a "non-supporter," of combustion. But this expression only applies to the test of a lighted taper, as a jet of oxygen may be burnt in an atmosphere of hydrogen, just as the latter will burn in one of oxygen.

This element when inhaled causes the voice to become squeaky. It is not poisonous, though, of course, it must be remembered that, if taken into the lungs, it displaces so much air, and would certainly cause insensibility if inhaled in too large a quantity.

SYNTHESIS OF THE ELEMENTS FORMING WATER.—When two volumes of hydrogen are mixed with five of atmospheric air in a long, stout glass tube provided with two platinum wires, standing over mercury, called an "eudiometer," and the electric spark passed between the platinum wires, a flash of light takes place, and expansion occurs; therefore a sufficient height of mercury must always be left in the tube: steam is formed, which condenses on the sides of the tube, and the bulk is found to be reduced to four measures, viz., the residual nitrogen left after one measure of oxygen has united with two of hydrogen.

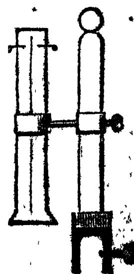


FIG. 480.—*A tube in which Platinum Wires are inserted, with Support to screw on the side of a Mercurial Trough.*

The experiment may be varied by mixing two volumes of hydrogen with one of oxygen; the mixed gases are then allowed to pass into a very strong vessel from which the air has been carefully removed, and when full the stopcock is turned off, and the electric spark sent through the mixed gases: light is seen, but little or no sound is heard; and this experiment may be repeated over and over again, until the moisture trickles down in

drops of water. The instrument was first used by the celebrated Cavendish, and is always called, after his name, the Cavendish bottle.

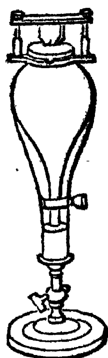


FIG. 481.—*The Cavendish Bottle*, Made of very thick glass, with platinum wires inserted in the stopper, which is held down by a brass framework.

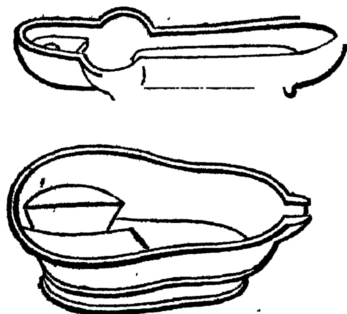
A jet of hydrogen gas burnt under a gas-jar containing common air soon lines the interior with moisture.

Dry hydrogen gas passed through a heated glass bulb containing cupric oxide, CuO—the black oxide of copper—deprives the latter of oxygen. Water is formed, and the equation worked out by comparing the loss of weight of the oxide of copper with the condensed water collected affords a very instructive class experiment.

The combustion of hydrogen and oxygen for the production of the lime light has already been alluded to in the article on Light.

The combination of the two gases is induced by the presence of finely-divided platinum, which glows and becomes red hot when a jet of hydrogen is directed upon it. Little balls made of pipeclay and spongy platinum are used to effect the combination of oxygen and hydrogen. In certain cases where the analysis of a mixture of gases is made, it is usual to heat the ball before inserting it into the mixed gases, standing in a tube over mercury in the mercurial trough, of which several convenient forms are shown in the next cuts (Fig. 482).

These troughs, as their name implies, are filled with mercury instead of water, because many gases are soluble in the latter.



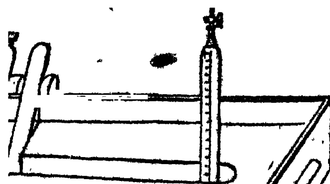


FIG. 482.—*Various forms of the Mercurial Trough.*

There is another compound of oxygen and hydrogen, called dioxide or peroxide of hydrogen, or hydric peroxide, H_2O_2. It acts as a powerful bleaching agent, and very quickly changes into oxygen and water; hence it is called oxygenated water.

This brief description of the three permanent gases, oxygen, hydrogen, and nitrogen, will hardly be complete without alluding to the five chemical compounds of nitrogen and oxygen.

1. Nitrous oxide, or laughing gas, symbol N_2O; made by heating dry ammonium nitrate in a retort; the salt decomposes into this gas and water.



$$NH_4NO_3 = N_2O + 2H_2O.$$

Ammonium nitrate. Nitrous oxide and water.

2. Nitric oxide, NO; a colourless gas, prepared by heating copper wire in dilute nitric acid. In contact with oxygen it forms red fumes soluble in water.

3. Nitric trioxide, or nitrous anhydride, N_2O_3.

4. Nitric tetroxide, or nitric peroxide, NO_2. Constitutes the chief portion of the red fumes produced when nitric oxide is mixed with oxygen gas.

5. Nitric anhydride, N_2O_5, prepared by passing dry chlorine gas over chloride of silver. It is nitric acid anhydrous, or free from water, and is a white crystalline substance, called also nitric pentoxide.

Nitric acid, the monohydrate HNO_3, of which 100 parts contain

N_2O_5	85·72
H_2O	14·28
	100·00

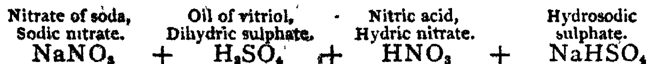
is one of the most important acids, or rather—to speak according to modern theory, "salts of hydrogen"—with which we are acquainted.

It can be made by acting on nitre with strong sulphuric acid, and is easily produced by distilling in a glass retort a mixture of the two substances.

This acid is a most powerful oxidizing agent: it will set fire to finely-powdered charcoal, or even straw, and is used in nearly every case where a metal has to be oxidized and dissolved. It was formerly called "aqua fortis," and is used extensively in the manufacture of gun cotton and in many other chemical processes.

Nitric acid, or hydric nitrate, is prepared by heating in a retort equal weights of nitre and oil of vitriol: red fumes are produced, and a very strong acid distils over—HNO_3—having a specific gravity of 1·517. On the large scale (when, for instance, it is required in the manufacture of gun cotton) large iron retorts lined with fire-clay are employed. Nitrate of soda is used because it is cheaper than nitre, and yields nine per cent. more acid.

The following equation explains the decomposition:



Nitrate of soda, Sodic nitrate. — Oil of vitriol, Dihydric sulphate. — Nitric acid, Hydric nitrate. — Hydrosodic sulphate.

$$NaNO_3 + H_2SO_4 + HNO_3 + NaHSO_4$$

The writer has paid several visits to the admirably arranged gun cotton factories of Messrs. Thomas Prentice and Co., Stowmarket, and is enabled to vouch for the truth of the following particulars, so ably described by "Engineering," November, 1857.

"The places at which the manufacture of gun cotton has ever been extensively carried on are but few in number. Soon after Schönbein, in 1846, made known the manner in which the material could be prepared, its manufacture was taken up to some extent at the powder-mills of Bouchet, near Paris, and in this country Messrs. Hall also commenced making it at their works at Faversham. At the latter works, however, a disastrous explosion occurred, which was attributed by the jury to the spontaneous combustion of the cotton; and after this the manufacture was discontinued, a large quantity of gun cotton which happened to be on stock at the time being buried. This was in July,

1847. In France also the manufacture was abandoned after a time, the French Commission being unable to produce a material possessing the required qualities; and in Prussia, where the manufacture of gun cotton had also been taken up by the Government, the experiments, which were carried on for eight years, were brought to an end by the blowing up of the factory. More recently, the process of manufacture advocated by Baron von Lenk was taken up strongly in Austria, where a special factory was erected at Hirtenberg; but Baron von Lenk's system did not prove perfectly successful, and in 1865 the Austrian Government gave orders that the ordnance which had been specially constructed to be used with gun cotton should be altered so that they could be used with powder, the use of gun cotton being from that date practically abandoned in the Austrian service.

"Notwithstanding these failures, however, the advocates of gun cotton—and notably Professor Abel, the director of the chemical department of our War Office—continued their researches; and, thanks to these, the manufacture of gun cotton has been very greatly improved, and is now established on a better basis than ever. At the present time gun cotton is being manufactured in this country at two places, the one being the Government powder-works at Waltham Abbey, and the other the extensive works of Messrs. Thomas Prentice and Sons, of Stowmarket, a firm who, by their extensive experiments on a manufacturing scale, have done much to bring the gun cotton manufacture to its present state. The two chief features in the processes now followed, as distinguished from those carried on by Baron von Lenk, are the pulping of the cotton after its conversion, and the admixture of this pulp, in some cases, with a certain proportion of plain cotton pulp, for the purpose of retarding the charges, or diminishing the rapidity of their combustion. The various processes followed during the manufacture of the cotton will, however, be best explained by a description of Messrs. Prentice's works at Stowmarket, which we now propose to give.

"The gun cotton factory of Messrs. Thomas Prentice and Sons is situated on the outskirts of the town of Stowmarket, by the side of a stream which furnishes a supply of water for washing purposes, and also drives a water-wheel by which the pulping machinery is worked. The factory consists of two distinct divisions, one devoted to the manufacture of mining charges, and the other to the production of cartridges for small arms, there being besides some shops common to both departments, where the conversion of the cotton and its formation into pulp are carried on.

"The raw material is received principally in the form of "waste." Formerly gun cotton was made exclusively from cotton wool; but Baron von Lenk introduced the use of cotton in the form of hanks or skeins, it being urged that these were more readily penetrated by the acids than the wool, which tended to cake into a mass when immersed. Now, however, it is found that cotton in almost any form answers equally well for the manufacture of gun cotton, the process now followed ensuring thorough conversion in all cases. The first thing done is to thoroughly cleanse the raw material. This is effected by boiling it in an alkaline solution, then drying it in a centrifugal machine, and then again boiling it in clean water. After the second boiling it is again partially dried in a centrifugal machine, and any remaining moisture is thoroughly removed, partly by exposing the cotton to the atmosphere, and partly by placing it on shelves in a drying-chamber heated artificially to about 120°. The drying of the cotton has to be very thoroughly effected, as any moisture which might

remain in it would, by combining with the acids used for conversion, generate heat and set up a destructive action. The centrifugal drying machines, which are extensively used at various stages of the manufacture, are of ordinary construction, each consisting of a cylinder with wire gauze sides, caused to revolve horizontally at the rate of from 500 to 800 revolutions per minute. A number of the machines at Stowmarket are worked from shafting driven by a horizontal engine, and others are driven each by a special engine placed close to the machine, these engines having their crank-shafts arranged vertically, and the fly-wheel of each engine being connected directly by a belt to the pulley on the spindle of the corresponding drying machine.

"The cotton, after having been thoroughly washed and dried, is weighed out in the drying-room into charges of ·1 lb., each charge being placed in a wooden box in which it is passed into the converting-room. There each charge is placed separately in a bath containing the mixed acids, the mixture in which the cotton is submerged consisting of three parts, by weight, of sulphuric acid and one part of nitric acid, this mixture being allowed to cool down—a process which occupies two or three days—before the cotton is placed in it. After immersion, the charges of cotton are strained until each contains only about ten times its weight of acids, and each charge is then placed in an earthenware jar and covered down. In order to prevent any heating of the cotton from taking place, the jars containing it are arranged in a kind of shallow trough through which a current of cold water is kept constantly flowing. The building in which the conversion of the cotton is effected is ventilated by a shaft in which an artificial current is maintained; but the ventilation can scarcely be called perfect, and it is doubtful whether the fumes arising from the acids could not be more completely removed by a series of flues connected with the shaft, and arranged so as to draw off the air from the floor of the room close to the bath in which the acids are contained. This system of ventilation has been advocated by General Morin, and has, we believe, been found very effective in similar cases.

"The action which takes place when the cotton is immersed in the mixed acids is as follows: Cotton, when pure, is one form of cellulose, and is an organic compound consisting of thirty-six equivalents of carbon and thirty equivalents of hydrogen—both combustible or oxidizable elements—together with thirty equivalents of oxygen, its composition being thus expressed by the chemical formula, $C_{36}H_{30}O_{30}$. Nitric acid, on the other hand, is a powerful oxidizer, and, if added to cotton and its action assisted by heat, it will rapidly oxidize not only the hydrogen, but a portion of the carbon which the cotton contains. In the manufacture of gun cotton, however, instead of the action of the acid being assisted by heat, care is taken to abstract any heat as soon as it may arise, and the action of the acid is thus moderated, only a certain proportion of the hydrogen being oxidized, and the carbon being unaffected. The nitric acid is, as we have said, mixed with three times its own weight of sulphuric acid, and the purpose fulfilled by the latter is that of intensifying the action of the nitric acid by absorbing the water with which even the strongest nitric acid is diluted, and also the water set free by the action of the nitric acid upon the cotton. The hydrogen removed from the cotton is replaced by an equivalent quantity of nitric acid, which has lost a portion of oxygen, and has thus become peroxide of nitrogen, and it is the introduction of this component which gives the gun cotton its explosive qualities. The peroxide of nitrogen is a powerful oxidizing agent—although not so powerful a one as the

nitric acid—and it only requires the aid of heat to enable it to oxidize the carbon and the remainder of the hydrogen contained in the cotton, and convert them into gases with explosive rapidity. The heat necessary for setting up this action is supplied when the cotton is ignited, and the action is aided by the oxygen contained in the cotton itself. The proportion of the hydrogen originally oxidized by the action of the mixed acids depends upon the strength of those acids, and upon the purity of the cotton subjected to them. According to Mr. Hadow, of King's College, who has devoted much time to the investigation of the chemical changes which go on during the process of conversion, there are four distinct varieties of gun cotton, each containing a different proportion of peroxide of nitrogen. When pure cotton and the most concentrated nitric and sulphuric acids—of the specific gravities 1·5 and 1·84 respectively—are used, he states that nine equivalents of hydrogen contained in the cotton are replaced by nine equivalents of peroxide of nitrogen, its composition being thus expressed by the formula, $C_{36}H_{21}9(NO_4)O_{30}$. This Mr. Hadow gives as the composition of Baron von Lenk's gun cotton; in the three other varieties he states that the numbers of equivalents of hydrogen replaced by peroxide of nitrogen are eight, seven, and six respectively. By the process of conversion the cotton is not altered in appearance, but it is materially increased in weight in the proportion of about 7 to 4.

"At Stowmarket, the cotton, after being exposed to the action of the acids for forty-eight hours in order to ensure its thorough conversion, is removed from the jars and placed in a centrifugal drying machine, which removes the greater proportion of the free acids. On its removal from the centrifugal drying machine it is plunged suddenly into a strong fall of water received by a tank, in which the gun cotton placed in the fall is allowed to remain for a short time. The object of placing the gun cotton in the fall of water, or 'drench-bath,' as it is called, is to ensure the sudden and complete submersion of the material, and thus avoid the heating and decomposition of the cotton which would take place at the surface of the water if the cotton were immersed gradually. On its removal from the drench-bath, the gun cotton is again dried in a centrifugal machine, and then placed in a bath through which a current of water constantly flows for forty-eight hours. After this it is again dried, and then placed in a second bath for a similar period, these alternate washings and dryings being repeated until the gun cotton has passed through eight baths successively, remaining forty-eight hours in each.

"After having been removed from the eighth bath and dried, the cotton is ready for pulping, a process which is in itself a washing of the most effective kind.

"The pulping machinery at Messrs. Prentice's works is driven by a water-wheel. The pulping machines, of which there are two, are similar to those employed in paper-mills.

"For making the mining charges, the pulp is first placed in a centrifugal machine, and as much water expelled as is possible by such means. When removed from the machine, the pulp is not completely dried; but the proportionate quantity of water which it contains is known, so that it can be weighed up into charges as accurately as if it were dried perfectly. The weighing of the dried pulp is effected by a number of girls, the weighing scales being situated in a light wooden building. Each charge, on being weighed, is placed in a small tin vessel, in which it is conveyed to the pressing-house, where the charges are again moistened with water. The sole object of temporarily dry-

ing the pulp is, in fact, to enable it to be accurately weighed out into charges, and after this weighing has been effected it is kept moist in all stages of its manufacture until it is subjected to the final drying process.

"The charges are first hand-pressed, and are then subjected to a more severe pressure by the aid of machinery. The hand-pressing is effected by boys, as follows: Each charge, after being moistened with water, is transferred from the tin cup containing it into a cylindrical mould or tube, the internal diameter of which is equal to the external diameter of the intended charge. At first these tubes were made solid at the lower end; but it was found that the gun cotton or pulp charge, when introduced into them, formed a kind of piston, below which the air contained in the tube became compressed, and under these circumstances it was found impossible to get the charges fairly home to the bottom of the tubes. This difficulty has been got over in a very ingenious manner. Instead of the tubes being made completely closed at the lower end, the latter is perforated, and the solid bottom on which the charge rests is formed by a piston, with which each tube is fitted. This piston is furnished with a rod, which passes up through the centre of the charge, forming a hole through the latter, which enables the charge to be ignited from end to end by the flash of the portion first lighted. In the case of charges the diameter of which exceeds about 1¼ in., the pistons of the moulds are furnished with two rods, one of these forming the central hole, and the other a hole nearer the circumference, in which the end of the igniting fuse can be placed.

"To return, however, to the process of pressing: the piston being first placed in the mould and pushed in a small distance, the charge is rammed in on the top of it, and then on the piston being forced down to the bottom of the mould by the aid of its rod, the atmospheric pressure on the top of the charge causes it to be carried down in close contact with the piston. A hollow plunger, perforated at the bottom and sides, is next placed in the mould, the end of this plunger having a hole or holes in it, through which the rod or rods of the piston can pass; and the whole is then placed under a hand-lever, by which the plunger is forced down on the charge, and the latter compressed to some extent. The charges, on being removed from the moulds above described, are next subjected to a more severe pressure by steam power. Two machines are used for this purpose, one of them, which is used for the larger charges, being a specially fitted up hydraulic press, and the other somewhat resembling a slotting machine in its general appearance. The slide of this latter machine, however, instead of carrying a cutting-tool, is fitted with three plungers, which act upon each charge successively. The charge to be pressed is placed in a cylindrical mould, carried by a horizontal circular table having an intermittent rotary motion. By one movement of this table the mould is brought under the first plunger of the slide, which partially compresses the charge, and, on the return stroke of this plunger, the further movement of the table brings the charge under the second plunger, which on making its next stroke completes the compression. A third movement of the table brings the mould under the third plunger, which on its descent forces the charge out of the mould, the latter having, by this third movement of the table, been brought over a hole through which the false bottom of the mould and the charge can pass. A fourth movement of the table brings the mould into a position where it can receive a fresh charge. The moulds and plungers are formed so as to allow of the escape of the water expressed from the charges, and the revolving table is supplied with several moulds, so that the processes of partial compression,

complete compression, and the expulsion of the charges are carried on simultaneously, there being always three charges under operation.

"For effecting the compression of the larger charges an entirely different apparatus is employed. This consists of a horizontal hydraulic cylinder, the main plunger of which is furnished with a head carrying a number of small plungers for compressing the charges, these plungers being arranged in parallel rows one above the other. Facing the plunger is the fixed head of the press upon which the pressure is received, and between this and the press cylinder is placed a block of zinc, perforated to receive the charges, and also another block, the use of which will be explained presently. Both these blocks are capable of being slid on one side, the lateral movement enabling the uncompressed charges to be placed in the zinc block. The second block, which is of iron, has, we should mention, a number of pieces of zinc let into it at the points at which the charges directly bear upon it. The method of using this apparatus is as follows: The charges to be compressed having been placed in the holes in the zinc block, the latter is brought into its proper position in front of the plungers, with the second block behind it, and secured by a simple contrivance provided for the purpose. Water is then forced into the press by pumps worked by a small steam engine close at hand, when the plungers enter the holes containing the charges, and compress the latter to the required extent. The water pressure is next removed, and the plunger allowed to recede to a sufficient extent to leave the second block loose. This block is then run on one side, and a box furnished with as many shelves as there are rows of charges being substituted for it, the water pressure is again put on, and the plungers, advancing, force the charges out of the holes in the zinc block into the box placed to receive them. The press is, of course, furnished with a number of zinc blocks and sets of plungers, corresponding to charges of different diameters, and the arrangement is found to be a very efficient one.

"The next process undergone by the charges after pressing is that of being covered with a peculiar kind of paper termed 'artificial vellum.' This artificial vellum, which is manufactured by Messrs. Prentice on their own works, is made by laying sheets of blotting-paper for a few seconds on the surface of strong sulphuric acid contained in a suitable bath. The paper, after being subjected to the action of the acid, is immediately washed by plunging into troughs containing water, and on its removal from these troughs it is ready for use. The process of manufacturing this material is a very interesting one to witness, the artificial vellum being a tough semi-transparent substance, so entirely different to the blotting-paper from which it is produced, that it is almost difficult to believe that the transformation could be effected by such simple means. The artificial vellum is cut into strips, rolled around the charges, and secured by paste, the operation of covering the charges being performed by girls.

"After being covered the charges are ready for the final process of drying; and this drying is effected by the aid of steam, the drying-stove being situated at some little distance from the sheds in which the other processes are carried on. The stove consists of a small brick erection enclosing the steam-pipes, the top of the brickwork being fitted with a number of vessels in which the charges to be dried are placed. The vessels are separated from each other by division walls carried up between them, so that, in the event of the contents of one vessel becoming ignited, the flame will not be communicated to the

other vessels, and they are protected from the weather by light hoods placed over them. The charges are dried at a temperature of about 140°, and efficient means are provided for ensuring that the temperature shall never rise above a perfectly safe limit.

"We have seen that, in the case of the mining charges, the pulp is, during the process of manufacture, subjected to very severe compression, and by this means a very great quantity of explosive matter is obtained in a small bulk. A mining charge, in fact, manufactured by the processes now followed at Stowmarket possesses an amount of explosive power six times as great as that of a similar bulk of gunpowder; and this concentration—if we may term it so—of the explosive material is in many instances of great value. Thus, when hard materials have to be blasted by charges contained in holes bored only to a moderate depth, a gun cotton charge, occupying only one-sixth the length of hole that would be taken up by a gunpowder charge of equal power, allows of a greater length of tamping being employed, and also concentrates the explosive action at greater distance from the working face. There is also now abundant evidence that gun cotton is in other respects a more effective explosive for mining and quarrying purposes than gunpowder. Thus, in breaking up large boulders by means of a charge inserted in a vertical hole bored from the top down to near the centre of the boulder, if a gunpowder charge is employed, its tendency is, if the block is of large size, to blow out a conical mass from the upper part of the boulder, the apex of this inverted cone being situated at the point where the charge is placed. With gun cotton, however, the case is different, it being found that it exerts a powerful splitting action below as well as above the point where the charge was situated. This effect appears to be due to the extremely rapid action of the gun cotton; but, whatever may be the cause, it is an effect which is found to occur in practice, and one which makes gun cotton particularly valuable for quarrying purposes."

There are some very remarkable circumstances connected with the ignition of gun cotton which show that almost any rate of combustion may be obtained by using a variety of heat-giving agents.

Thus, if a length of gun cotton yarn is fired with the incandescent charcoal or glowing spark at the end of a piece of string after the flame is blown out, it causes the cotton to burn slowly like a squib. If the flame of the burning string be used, or any other flame, the gun cotton puffs off with the usual rapidity of combustion.

A still more rapid combustion is secured by exploding gun cotton with fulminating mercury, when the destructive and rending power is tremendous. The writer witnessed some experiments kindly conducted by Messrs. Prentice at Stowmarket. Loose gun cotton may be laid by the side of a wall or stout wooden palisade, and if fired in the ordinary way with flame, little or no effect would be produced; but when the fire is communicated to the gun cotton by the concussion or combustion of fulminating mercury, the same kind of almost electric rapidity of combustion is conferred on the gun cotton, which explodes with a loud noise, and will then blow down the wall or wooden fencing with comparatively moderate charges.

There are, therefore, three distinct rates of combustion belonging to gun cotton, which are determined by the nature of the fire used:

1. A spark of incandescent charcoal causes it to burn slowly, like a pyrotechnic mixture.

2. With flame it puffs off rapidly.

5. By the fire and percussive power of fulminating mercury gun cotton explodes with the fearful violence belonging to trinitro-glycerine, which is supposed to have at least ten times more explosive force than gunpowder, and is so dangerous that its use in England is virtually arrested from the circumstance that no railway or ship will knowingly carry this terrible oil, which is prepared from glycerine by the action of concentrated nitric acid.

Glycerine—$C_3H_8O_3$—acted upon by strong nitric acid is converted into trinitro-glycerine, in which three atoms of typical hydrogen are replaced by three of nitric peroxide, $C_3H_5, 3NO_2, O_3$, affording another remarkable instance of the fact that all the most dangerous explosive bodies contain nitrogen.

"The Times" of 28th January, 1869, gives the following graphic account of the effect of various charges of gun cotton, fired with the detonating fuse, by Messrs. Thomas Prentice and Co., at Stowmarket. After many details of the manufacture of the gun cotton, the article concludes as follows:

"On quitting the practice-ground, the party set off to walk far afield, for though small charges of gun cotton may be fired close to a village, it is otherwise with quantities large enough to blow down palisades or break up trunks of trees. As the first experiment, a disc of gun cotton, weighing about 1 lb. 1 oz., was placed on the stump of a tree lately cut down, and ignited by an ordinary piece of miner's fuse. At the instant of ignition it was enveloped in flame, and sailed merrily about for the two or three seconds required for its combustion. The gas produced lifted it up and caused it to move. Then about half the quantity was placed on the same spot and ignited by a small detonating tube. A sharp, sudden report was heard, and the stump was found on inspection to be partly penetrated just where the charge had lain, while the twigs of the hedge close by suffered severely. On seeking for a new illustration a large tree-root was seen, which had been torn out of the ground, and offered among its gnarled and bossy structure a favourable position to deposit a charge. One of the discs, about 1 lb. 1 oz., was accordingly placed at the mouth of a small cave that seemed inviting. The gun cotton was not buried in the mass, but only laid, as it were, on a shelf perfectly open to the air. The gentlemen present retired to what they considered a safe distance, about fifty yards. There seemed to be some doubt about the effect. Is it possible that so small a quantity of gun cotton could rend such a mass, even if buried in it? Surely not when it is only laid on the floor of an opening. The moment of explosion is anxiously awaited. A man lights the fuse and runs for his life. There is a little smoke. Is the cotton burning as the first sample did? Wait a little yet. The tube has not given its sharp, cracking sound. One moment more, and then a report and a rush through the air of masses of wood—overhead, right, left, in front, everywhere! Soldiers who have known what it is to be under shell fire ducked to dodge a big lump of knotted wood that sprang sixty-four yards from its parent root, just clearing the heads of the party. It was only for a moment, and then everybody ran to see what had been done. The whole great root had simply been shattered to pieces, and grinning countrymen exclaimed, 'We hope you'll sarve a few more on 'em so for us.' A little awed by what they had seen, the visitors toiled and tumbled over a heavy ploughed field to see a row of palisades composed of three trunks, some of them 18 in. in diameter, and all sunk 4 ft. into the ground. Since the last explosion everybody had been a little more careful about lighted cigars, forgetting that a cigar or even a match would ignite the gun cotton in quite another fashion. A long tree-trunk lay touching the foot of the palisade,

and upon this 5 lb. of gun cotton was laid. Wires communicating with a magnetic apparatus were affixed to a detonating tube, which was placed in contact with one of the discs of gun cotton. 'But surely they won't all detonate, for only their circumferences touch at one point?' Wait and see; back over the heavy furrows a good 150 yards, no one being anxious to stand too near this time. The time of suspense was short, and then the explosion was heard. One mass of wood only was seen to plunge away from the palisade; it was the recumbent trunk upon which the cotton had been laid. The palisades themselves were standing, though a good deal damaged—no practicable breach. But there still remained a long space of palisading yet untouched, and here, instead of 5 lbs., 15 were laid, partly built on each other. The excitement began to increase. It was the old story of the targets and the guns, and now several people might have been found to back the palisades. Fuse and wires were placed. Everybody retired to a safe distance. Man's nervous organization is curiously elaborated, and it is not to be wondered at that there were several exclamations of, 'Please tell us just when you are going to fire.' Some persons put two good banks between them and the expected explosion, others sought the grateful shelter of a ditch. All were trying to combine the maximum of view with the minimum of danger. At last came the sharp, powerful crash, so unlike the dull roar of gunpowder, and this time there could be no mistake about the effect. Huge logs were seen performing summersaults at greater or less distances from the explosion, while smaller pieces, some about a couple of feet square, bounded like rabbits over the field. Men of science, officers, country gentlemen, and bumpkins were soon spread over the ploughed field, each striving to be first in at the death. On reaching the target the effect appeared to have been tremendous. In some places a tree-trunk had been cut in half, almost as with a rough saw, only not so straight; in others the solid wood was mangled, so that it could be pulled to pieces by the hand. Three logs had been cut down or smashed, and it was clear that no stockade or New Zealand pah could withstand such deadly effects for an instant. Exclamations of astonishment showed the mental impressions produced. '*Superbe!*' 'Prodigious!' 'Extraordinary!' 'Magnificent!' '*Mais c'est une maniere de faire les allumettes!*' And all this had been done by only 15 lbs. of the cotton. Three times the quantity made up into a cylinder could be carried with ease by a man at a run, who might also drag the ends of the two wires as they unwound from a reel kept in a position of safety. Is there no hint here for the colonists? No fire need be seen, for there is no match to light. Surely plenty of volunteers could be found to perform such work at night, and so restore the superiority of civilized man over savages. It had been contemplated to tie a ring of gun cotton round a living tree, and see if it could not be cut down; but there was not time enough. The experiments were over for the day, and the visitors returned to London, satisfied that they had seen a most marvellous phenomenon, and one which is only a first step to a whole array of novelties in the arts of war and of peace."

When the tremendous powers of modern artillery with improved gunpowder, and all the terrible refinements in the management of gun cotton, are considered, it is amusing to compare the latter with the bows and arrows used only three centuries and a half ago.

Extract from the "Edinburgh Courant."—"'I have seen a man who conversed with a man who fought at Flodden Field,' may be said by a venerable octogenarian gentleman, to whom we are indebted for the following most inte-

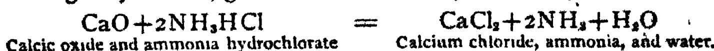
resting memorandum:—The writer of this, when an infant, saw Peter Garden, who died at the age of 126. When twelve years old, on a journey to London about the year 1670, in the capacity of page in the family of Garden of Troup, he became acquainted with the venerable Henry Jenkins, and heard him give evidence in a court of justice at York, that he 'perfectly remembered being employed, when a boy, in carrying arrows up the hill at the battle of Flodden.'"

		A.D.
It was fought in		1513
Add Henry Jenkins's age	169	
Les	11	
		158
Peter Garden	126	
Less his age when at York	12	
		114
The writer of this in 1865 aged		80
		1865

NITROGEN AND HYDROGEN, AMMONIA, $H_3N = 17$.

Many thousand years ago the Egyptians worshipped a god "Ammon," and it is said that as this compound was first obtained from a substance found near a temple devoted to the worship of this divinity, situated in the Oasis of Ammonium (*Siwah*), in the Libyan Desert, celebrated for its oracle and visited by Alexander the Great,—as the compound was first discovered near this temple, it was called Sal Ammoniac.

Quicklime and sal ammoniac, or ammonia hydrochlorate, NH_3HCl, when mixed and gently heated, give calcium chloride, ammonia, and water.



$$CaO + 2NH_3HCl = CaCl_2 + 2NH_3 + H_2O$$

Calcic oxide and ammonia hydrochlorate — Calcium chloride, ammonia, and water.

Ammonia is also given off when animal matter is heated, such as the horns of animals, and hence it was called "hartshorn." The first ammonia was doubtless obtained by the Arabs near the temple of Jupiter Ammon, by heating camels' dung.

Coal is the great source of ammonia, and this is not surprising when it is understood that it contains 2 per cent. of nitrogen.

Guano and other manures are applied to the land because they contain free ammonia, or other nitrogenous matter, ready to change into ammonia and to be assimilated by plants.

When sal ammoniac and quicklime are heated in a flask provided with a cork and tube, the gas may be collected over mercury. It is colourless, but possesses a very strong odour, affecting greatly the olfactory nerves, and causing a flow of water from the eyes, and hence is used as a refreshing stimulant, and is slowly evolved from mixtures called "smelling salts." Being lighter than air, it may be collected by holding a clean, dry bottle over the mouth of a flask containing the mixture of lime and ammoniacal salt; it is better, however, to pass the gas first through a bottle containing quicklime, in order to remove the moisture. Calcic chloride must not be used, as it absorbs ammonia and forms a definite compound with that body.

The specific gravity of ammoniacal gas is 0·590, air being 1·000; and therefore it fills an inverted bottle by displacement.

Ammonia cannot be collected over water, as it is so very soluble in that liquid. At the freezing-point water takes up 1,050 times its volume; at 59°, 727 times its volume; at 78°, 586 times its volume.

By conducting the ammoniacal gas into a series of Wolfe's bottles provided with safety tubes, the ordinary solution of ammonia may be prepared.

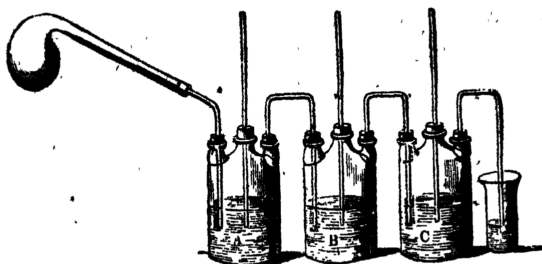


FIG. 483.—*Retort fitted to a series of Wolfe's Bottles,*
All provided with safety tubes.

Whilst the ammonia is being dissolved the water becomes very hot, and if kept at 60° by the application of a current of cold water, it will dissolve one-third of its weight of the gas, and, becoming specifically lighter, is then found to have increased in bulk by one-half. The specific gravity of the strongest solution of ammonia at 57° is 0·884, water being 1·000.

Various safety tubes are made when gases are passed into water or other solutions: one of the most elegant is that shown in the annexed cut. The object of a safety tube is to prevent the flask being crushed or the liquid returning into the materials by any sudden condensation and formation of a vacuum.



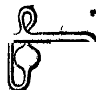


FIG. 484.
A Safety Tube, for Experiments with Gases, &c.

Blotting-paper coloured yellow with turmeric, called turmeric-paper, is instantly changed to a reddish brown when brought in contact with ammonia. Other alkalies affect the turmeric in the same manner; but the effect of ammonia is soon distinguished from others, because, on the application of heat to the paper, the ammonia is driven off, and the yellow colour of the turmeric is restored.

At a pressure of seven atmospheres, at 60°, ammonia (the gas) condenses into a liquid, and is used in M. Carré's freezing apparatus, which was exhibited on a grand scale at the Great French Exhibition of 1867.

Ammonia is formed by the union of three volumes of hydrogen with one of nitrogen, and its symbol is therefore H_3N.

There are two other compounds of nitrogen and hydrogen, which have not yet been obtained in an isolated form, viz.,

Amidogen, $H_2N = 16$.
Ammonium, $H_4N = 18$.

THE HALOGENS

(From ἅλσ, sea-salt),

CHLORINE, IODINE, BROMINE, AND FLUORINE.

A Group of Monads.

CHLORINE.

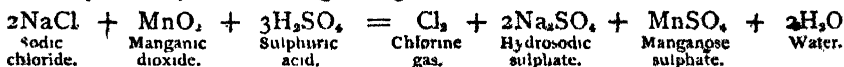
Symbol, Cl. Atomic weight, 35·5.

The fact that sea-salt is the chief source of Chlorine is sufficient to demonstrate its plentifulness; and its presence in soils, plants, animals, natural waters, sea-water, sea-salt, and rock-salt, all confirm the statement.

This gas, discovered by Scheele in the year 1774, is called chlorine from the Greek χλωροσ, green, in allusion to its peculiar yellowish-green colour.

The gas is easily procured by boiling hydrochloric acid with black oxide of manganese.

To obtain chlorine from salt, the latter is first mixed with the black oxide of manganese, and the sulphuric acid, diluted with water, is then added. The proportions are 4 parts by weight of salt, 3 of black oxide of manganese, 10½ sulphuric acid previously diluted with 7 of water. When these materials are carefully heated, the following change occurs:



$$2NaCl + MnO_2 + 3H_2SO_4 = Cl_2 + 2Na_2SO_4 + MnSO_4 + 2H_2O$$

$2NaCl$	MnO_2	$3H_2SO_4$	Cl_2	$2Na_2SO_4$	$MnSO_4$	$2H_2O$
Sodic chloride.	Manganic dioxide.	Sulphuric acid.	Chlorine gas.	Hydrosodic sulphate.	Manganose sulphate.	Water.

The gas must be carefully collected, and even the first portions mixed with air should be passed into a spare jar. If by accident the chlorine is inhaled, it causes the most violent irritation of the air-passages, and this occurs frequently when the chlorine is largely diluted with air, so that no inexperienced manipulators (boys, for instance) should be allowed to make it without a proper person to assist them. When very largely diluted with air, the odour is not disagreeable, reminding one of the smell of the sea.

Chlorine is much heavier than air; 100 cubic inches weigh 77·5 grains at 60° F., 30 in. bar. The density of this gas being 2½ times greater than air, it may be collected by displacement like carbonic acid, and, as recommended in the collection of ammonia, it is better to deprive the chlorine of moisture by passing it through a Wolfe's bottle containing a small quantity of sulphuric acid or calcic chloride.

The operator who employs this method must be very careful, and probably, to prevent accident, it is better to put warm water in the pneumatic trough, and use that in preference to the displacement method, because water at 60° dissolves quite twice its volume of chlorine, and thus all danger may be avoided by being able to watch the collection of the gas.

A lighted taper placed in chlorine gas burns with a reddish flame, an abundance of smoke being produced, in consequence of the chlorine combining with the hydrogen, whilst the carbon is deposited in part.

The great affinity (or desire to combine) between hydrogen and chlorine is shown in a very striking manner when equal volumes of the two gases are placed in a thin bulb of glass. If this bulb be held in a red light produced by passing the electric light through red glass, no change occurs; but directly the violet rays, obtained in excess by passing the light through violet glass, are allowed to fall upon the mixed gases, they explode, and hydric chloride is produced.

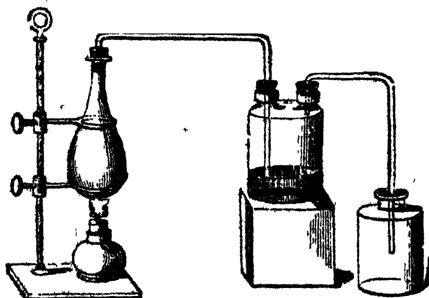


FIG. 485.—*Preparation and collection of Chlorine by displacement.*

If the eyes are protected by a screen of wire gauze held before the bulb, no harm can occur from the bits of very thin glass.

Hydrogen is now regarded as a metal, and analogy indicates more "presumptive evidence" that this is the case, because other metals, though they do not explode with chlorine, are quite ready to burn, and do, in fact, take fire when sprinkled in fine powder into this gas, viz., finely-powdered antimony, copper, and gold in leaf, also arsenic, likewise phosphorus.

Chlorine has very powerful bleaching properties, and is in effect an oxidizing agent. It is always ready to unite with the hydrogen of water: the latter undergoing decomposition, oxygen is eliminated; and this in the nascent, condensed state, like ozone, destroys many vegetable colours.

A little solution of sulphate of indigo is rapidly bleached when shaken with some chlorine gas.

Chlorine gas unites with oxygen in various proportion,

1. Hypochlorous anhydride, $Cl_2O = 87$.
2. Chlorous anhydride, $Cl_2O_3 = 119$.
3. Chloric peroxide, $ClO_2 = 67{\cdot}5$.

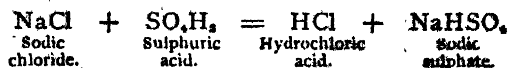
From the two first, by union with hydrogen, are the following:

1. Producing hypochlorous acid, $HClO = 52{\cdot}5$.
2. " chlorous acid, $HClO_2 = 68{\cdot}5$.
3. " *no known acid yet obtained.*
4. *(No corresponding oxide of chlorine yet discovered)*; producing chloric acid, $HClO_3 = 84{\cdot}5$.
5. *(No corresponding oxide of chlorine yet discovered)*; producing perchloric acid, $HClO_4 = 100{\cdot}5$.

THE COMPOUNDS OF CHLORINE WITH HYDROGEN.

HYDRIC CHLORIDE (Spirit of Salt), HYDROCHLORIC ACID (Muriatic Acid), $HCl = 36{\cdot}5$.—As already stated, equal volumes of chlorine and hy-

trogen exposed to the strong light of day or violet light, combine and form the same volume of hydric chloride. This important acid is prepared by distilling metallic chlorides with sulphuric acid, and, of course, the cheapest is sodic chloride, or common salt. The following equation explains the decomposition:



$$\underset{\text{Sodic chloride.}}{NaCl} + \underset{\text{Sulphuric acid.}}{SO_4H_2} = \underset{\text{Hydrochloric acid.}}{HCl} + \underset{\text{Sodic sulphate.}}{NaHSO_4}$$

The same apparatus (Fig. 483, p. 567) may be used for dissolving hydrochloric acid in water, and therefore, being so soluble in the latter, it must be collected in the mercurial trough, or by displacement in dry bottles. A hundred cubic inches at 60° F., 30 in. bar., weigh 39·64 grains.

Under a pressure of forty atmospheres it is condensed into a fluid.

The ordinary solution in water as sold in the shops is an almost colourless fluid. The strongest commercial acid contains 4·2 per cent. of real acid, and has a specific gravity of 1·210. It is impure, and contains iron, arsenic, &c.

The gas extinguishes flame, and is not combustible. The solution of the acid gas in water is most useful for analytical and other purposes in the laboratory.

The compound of chlorine with nitrogen (HCl_2N, Cl_3N), called chloride of nitrogen, is most dangerous and explosive, and should never be prepared, as it is running a useless risk, the properties of the compound being already known.

Chlorine also unites with carbon, forming at least four distinct compounds.

IODINE.

Symbol, I. Atomic weight, 127.

Discovered originally by Courtois in the waste liquors obtained in the manufacture of carbonate of soda (sodic carbonate) from the lixiviation of the ashes of seaweed, Iodine is prepared from kelp, the fused ashes of burnt seaweed, and is largely manufactured on the western shores of Scotland and Ireland. The kelp is first broken up into small pieces, and digested with water; the latter dissolves about one-half, consisting of the chlorides and carbonate of soda, also chloride of potassium and iodide of sodium (sodic iodide) and other salts; these are in great measure deposited by evaporation and crystallization, and as the iodide of sodium is the least soluble, it remains behind in what is called the "mother liquor" or "bittern;" this, placed in a proper vessel and distilled with black oxide of manganese and sulphuric acid, in the same manner as already described in the preparation of chlorine from salt, oxide of manganese, and sulphuric acid (p. 568), yields the violet vapours of iodine,—so called from the Greek ἰώδης, purple.

An experiment on the small scale may be made by gently heating a little solution of iodide of potassium in a flask with oxide of manganese and sulphuric acid, when the iodine is rendered apparent by the colour it imparts to the air in the upper part of the flask. (Fig. 486.)

Iodine condenses into a dark grey solid, having a brilliant metallic lustre. It is extremely volatile, rising in vapour below the freezing-point of water: it

freezes at 225°, and boils at 347°, emitting an odour very much like that of chlorine. It has feeble bleaching powers, and is slightly soluble in water.

It attacks certain metals, forming iodides with them, and it may be again separated by chlorine. Starch is the most delicate test for iodine, with which it forms a purple compound. The colour, obtained by pouring a little tincture of iodine into a flask containing some starch, disappears when the fluid is boiled, but returns again after it has cooled. Iron or zinc filings placed with iodine and water in a beaker glass are soon converted into iodides and dissolved in the water.

Phosphorus takes fire when brought into contact with iodine. Iodine is used extensively in medicine; but another and most important application of this element deserves special notice here in connection with the art of photography, and the Author is indebted to his friend, Mr. John Spiller, Hon. Sec. of the Photographic Society, for the following *résumé*.

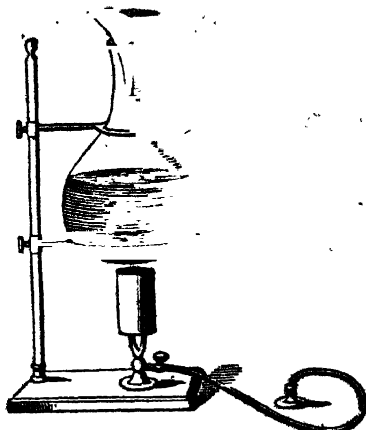


FIG. 486.—*Production of Iodine Vapour from Potassium Iodide.*

THE ART OF PHOTOGRAPHY.

The invention of Photography as a practical art may be said to date from the year 1839, when M. Daguerre, in France, and the Hon. H. Fox Talbot, in this country, described almost simultaneously the respective processses which have since been identified with their names. The daguerreotype is commonly known as the process of obtaining a photographic impression upon a highly polished silver, or electro-silver, plate, the surface of which is rendered sensitive to light, or rather to the *actinic* principle of the sun's rays, either by the action of iodine alone or a mixture of bromine and iodine. Exposing the plate so prepared to light in a properly constructed camera obscura, and afterwards rendering manifest the graduated change induced upon the coated surface of the metal by placing it under the influence of mercury vapour, which then is found to attach itself most abundantly to those parts of the image where the light has acted with the greatest intensity, thereby forming a lustrous amalgam, which adheres firmly to the plate, even when the excess of unaltered iodide of silver is removed by washing with an aqueous solution of hyposulphate of soda or other chemical solvent. The daguerreotype image is sharp and delicate, and when coloured of a warmer tone by the final application of a gold salt (using by preference the *sal d'or* of MM. Fordos and Gelis), is admirably adapted to portraiture, to the delineation of microscopical subjects, and to the recording of celestial phenomena. Its chief drawback lies in the circumstance that the silver plates are liable to become tarnished in the course of time, however carefully mounted, and, further, that these photographs are somewhat difficult of multiplication.

Mr. Talbot's process, originally known as the "calotype," but afterwards named in honour of the inventor the "Talbotype," depends likewise upon the

sensitiveness to light of the iodide of silver; but the mode of producing the argentic compound, the medium upon which it is spread, and the process of developing the *latent image*, are so totally different, that it must be regarded as a specifically distinct application of chemical science.

Plain or waxed paper is immersed in a solution of iodide of potassium, and after a few minutes removed, drained, and hung up to dry. In this condition it is stored ready for use, and may be *sensitized* by being floated on a solution of nitrate of silver of a sufficient degree of concentration to leave an excess of the latter in the pores of the paper, and necessarily in immediate contact with the precipitated particles of iodide of silver. Whilst still slightly moist, the sheets of paper are enclosed in suitable dark slides, and are ready for exposure in the camera; or this operation may be deferred for any time short of twenty-four hours. The pictures are developed by dim candlelight, or in a room from which all but the yellow non-actinic rays of daylight are cut off by the use of deep orange panes of glass or curtains of yellow calico, by the following process: Gallic acid, in aqueous or weak acetic solution, is first washed over the paper, and, as soon as the photographic image has become distinctly visible, a mixture of gallic acid and aceto-nitrate of silver is applied, which gradually augments the intensity of the developed image until the high lights in the original are represented in the picture by intense blacks, and all the gradations of shading appear to be truthfully rendered, but inversely, in the *negative*. Washed and fixed by the application of hyposulphate of soda, as suggested by Sir John Herschel, the operator is in the possession of a permanent record, from which an innumerable succession of *positive* pictures, true to nature, may be obtained by sun-printing upon paper prepared with the chloride of silver, as afterwards explained. The peculiar advantages of the talbotype were the facilities it afforded to the landscape photographer, who, preparing his paper early in the morning, could always rely upon obtaining a number of good negatives by development in the evening. The comparatively long period required for exposure in the camera (from five to ten minutes) necessarily limited the use of this process to objects of still life; but great results, even in portraiture, were obtained by those who perseveringly devoted themselves to the surmounting of a number of mechanical difficulties connected with the selection of the paper and its mode of preparation. An early improvement consisted in the use of the argento-iodide of potassium, as prepared by dissolving iodide of silver in a tolerably concentrated solution of iodide of potassium. This double salt applied to the paper as a single wash furnished the means of preparing a superior description of iodized paper of a fine primrose tint, by simple immersion, partial drying, and afterwards floating on water to effect the removal of the alkaline iodide. With this material a very weak gallo-nitrate of silver was commonly employed for sensitizing, and the papers after exposure showed a faint image prior to being subjected to the development process already described.

The collodion process, invented by Mr. Scott Archer in 1851, has almost entirely superseded the two earlier systems of photography. It cannot be said, however, to be altogether independent of Mr. Fox Talbot's original principle, for the same condition of iodide of silver is employed, and very similar methods of development and fixing are resorted to. The pictures are obtained upon glass plates coated with a film of exquisitely sensitive material, consisting of particles of newly precipitated iodide of silver, supported in a transparent network of pyroxyline or gun cotton, as left by the evaporation of

the ethereal mucilaginous material now so well known under the name of *collodion*. For the production of this film of iodide of silver, a suitable quantity of iodide of potassium, or of cadmium, is dissolved in alcohol and mixed with the plain collodion, and the necessary silver is supplied by immersion of the coated glass plate in an upright "dipping bath" of nitrate of silver. Removed after a few minutes' contact, the plate is ready for the camera, and should be exposed without delay. Upon being taken back to the operating-room to undergo the process of development, there is absolutely nothing in the shape of a picture visible upon the plate until the developer is applied, which solution may either consist of the green sulphate of iron, or a dilute solution of pyrogallic acid in water rendered slightly acid with acetic or other organic acid. The operation of these chemical agents is powerfully reducing, and they consequently effect the reduction of the soluble argentic salt remaining in excess upon the plate, the particles of finely-divided metallic silver so precipitated being deposited by preference upon the nuclei of altered molecules of iodide of silver, with gradations varying according to the intensity of the light which has acted on those parts. Thus, then, is obtained, with proper exposure in the camera, an exquisitely delicate negative image in pure silver upon a stratum of collodion, containing still some yellow iodide of silver in admixture. The latter is removed by washing with a solution of hyposulphate as before, and the plate is well rinsed, dried, and protected with a coating of varnish.

From the negatives, whether obtained by the collodion or the calotype process, a great number of positive impressions may be prepared by following the manipulation of what is called the *printing process*. For this purpose it is usual to employ the chloride of silver spread upon paper with an addition of egg albumen and an excess of the nitrate of silver.

The ordinary mode of proceeding consists in applying to one side of a sheet of paper a mixture of well-beaten white of egg, salt, and a proportion of water varied according to the degree of lustre desired in the finished photographs: for general purposes the following instructions may be followed:

White of egg	10 oz.
Water	5 "
Common salt	½ "

For landscapes and portraits of large size the quantity of albumen may be advantageously diminished, whilst, on the other hand, it may often be necessary to limit the addition of water when the maximum degree of sensitiveness and delicate rendering of detail in *cartes de visite* or other small prints are the objects sought. The mixture of materials above prescribed is poured, without agitation, into a flat dish, and one side of the paper is then slowly laid down upon the surface of the salted albumen. After two minutes' contact the sheet is again carefully removed, and hung up to drain and dry. In this state the salted albumenized paper may be preserved for a great length of time, and when required for use, it is necessary to float it for two or three minutes upon a 50-grain solution of nitrate of silver.

In order to perform this and most of the subsequent operations with success, it is customary to screen the light entering the windows of the photographic room by interposing one or more folds of yellow calico; for, when dry, the sensitized paper will become bronzed or blackened by a comparatively short exposure to the sun. In this sensitized condition, the prepared side of

the paper is brought into contact with the collodion face of the negative, and the two held together under slight pressure in a properly constructed printing-frame, in which it is now ready to be exposed to the light, observing only the precaution of not subjecting the varnished negative to the direct and hot rays of a midsummer sun. Examined by lifting one-half of the hinged back and the paper from the face of the negative, the progress of the printing operation may be watched, and interrupted at the proper stage—when the intensity of the print has become slightly deeper than the finished result is required to be. At the end of a day's work it is customary to wash, tone, and fix the prints, which is carried out by immersing in water, for ten or twenty minutes, the prints so obtained, pouring off the excess of nitrate of silver solution, and leaving them in a fresh supply of water, ready for the toning operation.

Take	Chloride of gold	4 grains
	Bicarbonate of soda	15 „
	Acetate or phosphate of soda . .	
	Water	1 pint

The washed prints are separately transferred to this solution, and immersed for a period of time (two or three minutes) sufficient to effect a change of colour from foxy red to bluish purple. When this stage is reached they must be quickly removed into a capacious dish of water, and, thus toned, are ready for the fixing bath, composed of

Hyposulphite of soda	4 oz.
Water	1 pint

They will need to be very thoroughly washed by immersion either in a running stream of water, or in dishes the contents of which are frequently changed. The prints when dry are trimmed and mounted.

Other systems of photographic printing are occasionally adopted; thus, instead of employing the albumenized paper just now described, the use of plain salted paper for a small surface is resorted to, following a similar treatment in the printing, toning, and fixing operations; or, lastly, a somewhat novel mode of reproduction consists in making use of the very beautiful invention of Mr. G. Wharton Simpson, known as the *collodio-chloride* process. For this purpose a collodion, specially prepared from chloride of strontium and nitrate of silver in a vehicle containing the constituents of plain collodion, is found to possess the singular property of holding in suspension for a great length of time the impalpable particles of chloride of silver produced by the admixture of the two above-mentioned salts. Preserved always in the dark, this collodio-chloride preparation is poured over a plate of white enamelled glass, the coated side of which, when dry, is placed in contact with the negative to be printed, and the delicate image resulting from its exposure to light is fixed in the same manner as an ordinary collodion picture.

Wonderfully fine results are obtained also by certain systems of camera printing, or inversion of the process by which the glass negative is originally obtained. These developed pictures, toned with gold and mounted with an opaque white gelatine backing, have attracted much attention under the name of "Eburneum" photographs. If otherwise treated as transparencies, they become very suitable for exhibition in the magic lantern, or, with ground glass behind, they have been made to do duty in the stereoscope.

The so-called "carbon photographs" are prints obtained upon a tissue of

gelatine and bichromate of potash, with which has been incorporated carbon itself in the form of lampblack or Indian ink, or any equivalent dark-coloured pigment. By exposure to light the gelatine becomes hardened and insoluble, so that in the high lights of the picture much of the colouring matter is locked in the material, whilst in the protected portions of the print all the gelatine and pigment washes away, leaving the white paper or other basis of the transfer freely visible, and the half-tones are properly represented by graduated layers of altered gelatine, the varying thicknesses of which are dependent upon the intensity of the light's action.

The latest modification of the principle involved in the carbon printing process of Mr. Swan is one by which the final results are obtained by mechanical printing, from a metal block which bears the impress of the delicate gelatine relief resulting from a mode of working similar to that just now described. This metallic plate is charged with a liberal supply of warm ink (composed of gelatine and suitable pigments), then covered with white paper, and pressure is immediately applied for the purpose of driving out all the extraneous ink. When cold, the print is lifted from the metal block, and fixed by immersion in alum-water, which renders the gelatine completely insoluble. This mode of proceeding is the invention of Mr. Walter B. Woodbury, and the resulting proofs are commonly known as "Woodburytypes." Their exquisite delicacy brings them into favourable comparison with the best results of the silver printing process; and it will be remarked that when the gelatine matrix is once procured, the subsequent operations are entirely independent of the action of light.

Iodine, like chlorine, unites with hydrogen, forming an acid called hydriodic acid or hydric iodide. The symbol of this acid is HI, and its atomic weight 128.

Hydriodic acid is a gas which fumes strongly when brought in contact with the air: it is very heavy, the specific gravity being 4·443. Like hydrochloric acid, it may be collected by displacement, and is composed of one volume of hydrogen and one of iodine, forming two volumes of hydriodic acid.

There are some oxides of iodine and two important acids:

Iodic acid or hydric iodate (symbol, HIO_3);
Hydric periodate or periodic acid (symbol, HIO_4);
Iodic pentoxide (symbol, I_2O_5);

and iodine appears to have a stronger affinity or attractive power for oxygen than either chlorine or bromine. It unites also with chlorine and bromine, and forms an explosive compound with nitrogen, NI_3, in which an analogy in molecular composition to ammonia is at once apparent, three atoms of hydrogen being replaced by three of iodine.

BROMINE.

Symbol, Br. Atomic weight, 80.

This element (perhaps a *quasi* element, for there is every probability that it will one day be resolved into another and more elementary condition) bears a close resemblance to chlorine, and has many properties in common with that element. It was discovered by Balard in 1826, in the same liquid, "bittern,"

which furnished iodine, with this exception, that Balard's "bittern" came from the mother liquor of the salt marshes of Montpellier.

Near Kreuzenach, at a place called Theodorshall, is a salt-spring, and from this water a considerable quantity of bromine is obtained.

The iodine, as in the instance of the mother liquor of varec, is first got rid of by passing chlorine gas into the liquor until a sample gives no precipitate with chlorine; the residual fluid is then mixed with black oxide of manganese and sulphuric acid, and distilled, and the same kind of change that occurs in the preparation of chlorine or elimination of iodine takes places in this case also, and bromine is obtained.



$$2MgBr + 2MnO + 2H_2SO_4 = Br_2 + Mg_2SO_4 + Mn_2SO_4 + 2H_2O.$$

Bromine is extremely volatile: a few drops thrown into a bent tube soon fill it with red vapour. It is a non-conductor of electricity. At $-22°$ C. it assumes the solid state, and is then of a dark greyish lead-colour, with a partial metallic lustre.

The smell of bromine is, like chlorine, very suggestive of the odour of sea air. In a concentrated state the vapour is irritating, and it was from this circumstance that the element was named *βρωμος*, a stink.

The specific gravity of bromine in the state of vapour is 5·540; in its ordinary liquid state the specific gravity is 3·187 at a temperature of 32° F. Bromine, like chlorine, is a powerful bleaching agent: it is very corrosive, attacking cork and wood, which are changed yellow and become disintegrated and rotten. A very little drop will kill a small animal. The same atomic relation to hydrogen observed with chlorine and iodine occurs with this element.

Hydrobromic acid or hydric bromide (symbol, HBr; atomic weight, 81) consists of equal measures of hydrogen and bromine vapours united, but retaining the same volume. The compounds of oxygen and bromine, although numerically less, are very similar to those of chlorine and oxygen.

Hypobromous acid, HBrO;
Bromic acid or hydric bromate, $HBrO_3$.
Perbromic acid or hydric perbromate, $HBrO_4$

There is also a compound of bromine with chlorine called bromous chloride ($BrCl_3$), and a detonating oily fluid, bromide of nitrogen, analogous to chloride of nitrogen. A fluoride of bromine likewise exists: in fact, bromine unites with all the elementary bodies. Altogether, bromine holds an intermediate position between chlorine and iodine. It can expel the latter element from certain compounds, and is in its turn expelled by chlorine.

If the atomic weight of iodine be added to that of chlorine, and divided by two, the mean is as nearly as possible the atomic weight of bromine.

FLUORINE.

Symbol, F. Atomic weight, 19.

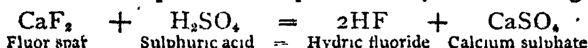
This element appears to have evaded the usual searching powers of the analytical chemist, and for a long time could not be procured in the elementary state. It seems, however, to be satisfactorily determined that it can be liberated from the trammels of combination by acting on dry argentic fluoride or silver fluoride with dry iodine; it then appears as a colourless gas, which

has no power upon glass, and is rapidly absorbed by a solution of potash, but remains permanent over mercury.

Fluor spar is found in Derbyshire and in all the galena (plumbic sulphide) veins which traverse the coal formations of Durham, Cumberland, and other places, and is most frequently crystallized in the cubic form. The red varieties have been called *false ruby*, the yellow *false topaz*, the green *false emerald*, and the blue *false sapphire* and *amethyst.* The variety of fluor spar that becomes phosphorescent when heated is called "chlorophane," from the green light it emits.

Because it has been used by the metallurgists as a flux for ores, particularly those of iron and copper, it derives the name of "*fluor*," from *fluo* to flow; its modern scientific name is calcium fluoride (CaF_2). Fluorine is also contained in the mineral termed cryolite ($3NaF, AlF_3$), a double salt of sodium and aluminium fluoride, and an important source of the metal aluminium. As the teeth contain a minute quantity, it is evident that the body is supplied with this element from the foods required for the support of man.

The most important compound is that which it forms with hydrogen—called hydro-fluoric acid or hydric fluoride ($HF = 20$). It is obtained, like hydrochloric acid, by distilling one part of fluor spar with three parts of strong sulphuric acid, and the decomposition is represented by the following equation:



$$\underset{\text{Fluor spar}}{CaF_2} + \underset{\text{Sulphuric acid}}{H_2SO_4} = \underset{\text{Hydric fluoride}}{2HF} + \underset{\text{Calcium sulphate}}{CaSO_4}$$

The fluor spar and sulphuric acid must be heated in a leaden retort, or, better still, in one made of platinum, and the vapour, hydric fluoride, is collected in a receiver—usually a bent leaden or platinum tube surrounded with a freezing mixture. The metals, lead or platinum, should be used, as hydric fluoride acts so vigorously on glass.

It would appear from the researches of Louzet that the acid prepared in this way contains water, and by distilling it again with phosphoric anhydride, a colourless gas of a very lung-exciting nature is obtained, which does not act like the ordinary acid on perfectly dry glass. This acid united with two atoms of water increases in specific gravity from 1·060 to 1·150 ($HF, 2H_2O$). It does not undergo any change when distilled, and boils at 248° F. This acid acts upon a great number of metals, its hydrogen being displaced by them. The acid is used for etching on glass, and is now (like other once rare chemical compounds) employed most skilfully in the formation of elegant patterns on that vitreous body.

CARBON.

Symbol, C. Atomic weight, 12.

Every tyro in chemistry is now ready to speak profanely of the diamond as only a bit of hard and nearly pure carbon. The portraits of Faraday and Wheatstone have already been given in this work, and the series is hardly complete without that of the learned man who has lately, like Faraday, passed away from us. Brewster's name is introduced here because, amongst the thousand and one clever papers on scientific subjects that he wrote, we find one devoted to what he terms pressure cavities in the diamond, which will be alluded to hereafter.



FIG. 487.—*Portrait and Signature of Sir David Brewster.*

David Brewster was born at Jedburg on the 11th December, 1781, and died in 1868. His name will always be associated with the kaleidoscope, and the discussion of other and more abstruse points in the science of optics.

Carbon or charcoal can be obtained from various sources. Bone-black or animal charcoal is obtained by subjecting bones to a low red heat in closed iron cylinders, the volatile matter, ammonia, &c., being allowed to pass into proper receivers.

It is most usefully employed as a deodorizing agent in the purification of raw sugar, &c., and its deodorizing properties and power of condensing the putrid effluvia of decomposing animal or vegetable matter is very well understood, and used in the openings of the shafts of sewers, or, more agreeably, in the filtration and purification of water containing organic matter.

Wood charcoal is now made very carefully from willow or alder, by heating them in closed iron cylinders, and, when prepared in this manner, is used in the manufacture of gunpowder. Common wood charcoal used for heating purposes is prepared in a ruder fashion by the charcoal-burners. Lampblack, or finely-divided charcoal, is obtained by the slow combustion of resin or tar: these bodies yield hydro-carbon, and, as the air is only partially admitted, the hydrogen is removed, forming water, whilst the carbon is deposited. By exposing common lampblack to a red heat in a closed iron vessel, the tarry matter is then thoroughly ignited, and a very pure form of carbon obtained.

Coke, the charcoal of coal, is made in large quantities during the distillation of coal in the manufacture of coal-gas.

A very hard form of charcoal is gradually deposited in the gas retorts, which is used instead of platinum in the nitric acid cell of the voltaic battery, called Bunsen's, and likewise for the terminals of the poles of the voltaic battery in the production of the electric light. This kind of charcoal is sometimes spoken of as graphite; but, when so styled, should be called "artificial," as the real graphite is a natural and nearly pure form of carbon.

Plumbago, black lead, or graphite is a most useful form of mineral carbon: it used to be obtained from the mines at Borrowdale, but is now procured from mines in Asia and other places. The finer kinds of plumbago were formerly boiled in oil, and then cut into tables or pencils; but now the dust or powdered plumbago is compressed and employed extensively in the manufacture of lead pencils. It is also used for brightening grates and other ironwork, and keeping them free from rust. Graphite is now extensively used in the manufacture of very refractory crucibles, and as an anti-friction material.

By combining charcoal with wrought iron, the latter becomes extremely fusible. If this compound of carbon and iron be melted and allowed to cool slowly, it will be covered with scales, which on examination are found to be identical with plumbago or black lead.

Some meteorites contain graphite or black lead, mechanically diffused through the mass of iron which has fallen from the skies.

Brodie has shown that by acting on graphite with an oxidizing agent, such as chlorate of potash and sulphuric acid, a product is obtained that does not present any characteristic different from that of ordinary graphite. If, however, it be heated in a test-tube, it swells up and presents a very remarkable appearance: the graphite partly oxidized gives off steam, and returns again to its original condition. Carrying the oxidizing process still further, the same chemist has converted graphite into graphitic acid ($C_{11}H_4O_5$). By acting repeatedly on this substance with chlorate of potash and nitric acid, it forms perfectly transparent thin crystals: when a few of these are heated in a platinum dish, incandescence and a slight explosion occurs, and a large quantity of soot is evolved: the graphite, by the roundabout process of oxidation

and conversion into graphitic acid, and subsequent heating, is now changed to ordinary charcoal. The experiment with the graphitic acid is a very curious one, the quantity of charcoal evolved in the form of soot is so enormous.

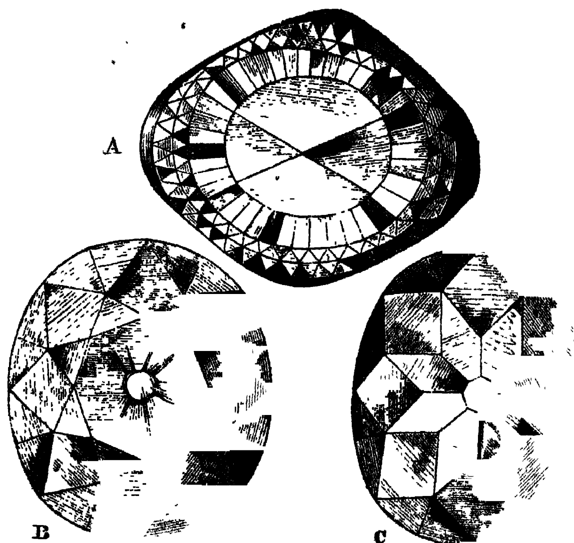


FIG. 483.—*The Koh-i-Noor before and after re-cutting.*

A, the Koh-i-Noor before re-cutting; B, back view of same after re-cutting by Mr. Coster; C, front view after re-cutting.

The diamond, the purest form of natural carbon, is well represented by the most costly of the crown jewels called the Koh-i-Noor.

"The history * of this gem has been so often told that it would be superfluous to give any lengthened notice of it. The Hindoo accounts deduce it from the time of the god Krischna. We know, however, for a certainty that it was in the treasury of Delhi, and was taken at the conquest of that city by Ala-ed-Din. Thence it came into the possession of the Sultan Baber, of the Mogul dynasty, in 1526. This prince esteemed it at the sum of the daily maintenance of the whole world. The jewel was seen by Tavernier among the jewels of Aurungzebe: it had, however, been reduced by the unskilfulness of Hortensio Borgio from 793 carats to 186 carats—the weight it possessed at the Exhibition of 1851. The Emperor Aurungzebe was so incensed that he refused to pay Borgio the sum agreed on for the cutting, confiscated the whole of his possessions, and with great difficulty was persuaded to leave him his head. Nadir Shah, the conqueror of India, by means of an artful trick obtained possession of this stone, and from the hands of his descendants it passed into the possession of Achmed Shah. His son, Shah Sujah, was in turn forced to return it into the hands of Runjeet Singh. After the capture of

* "Diamonds and Precious Stones." By H. Emanuel.

Lahore, at the time of the Sikh mutiny, it fell into the hands of the British troops, who presented it to Her Majesty Queen Victoria on the 3rd of June, 1850.

"This brilliant was shown at the Exhibition of 1851. It then had an irregular form, with several hollows in its sides and base, and showed clear traces of natural cleavage planes; there were also several fissures or cavities in its surface. It was shown to several of the first scientific men of the day, Sir David Brewster among the number, who were of opinion that the stone presented great difficulty in the way of cutting. After much consideration it was entrusted to Mr. Coster, of Amsterdam, who expressed himself confident as to the result of re-cutting; and the event proved the correctness of his judgment, for the stone, though of less weight than before, possesses nearly the same size, and instead of being a lustreless mass scarcely better than rock crystal, it has become a brilliant matchless for purity and fire.

"This diamond now weighs $106\frac{1}{16}$ carats, and forms part of the crown jewels of England."

Sir David Brewster makes the following remarks on the Koh-i-Noor in his paper in the "Transactions of the Royal Society of Edinburgh, 1862," and entitled

"ON THE PRESSURE CAVITIES IN TOPAZ, BERYL, AND DIAMOND, AND THEIR BEARING ON GEOLOGICAL THEORIES.

"In the Koh-i-Noor diamond, which the Prince Consort kindly permitted me to examine in 1852, I found three black specks, scarcely visible to the eye, but which the microscope showed to be irregular cavities surrounded with sectors of polarized light. In the two smaller diamonds which accompanied the Koh-i-Noor there were also several cavities surrounded with luminous sectors, and the same polarizing structure which indicated the operation of compressing and dilating forces. In order to obtain more information on this subject, I examined nearly fifty diamonds lent me by Messrs. Hunt and Roskell, and in almost all of them I found numbers of cavities of the most singular forms, round which the substance of the stone had been compressed and altered in a remarkable manner. The shapes of the cavities sometimes resembled those of insects and lobsters, and the streaks and patches of colour in polarized light were of the most variegated kind. It seems, indeed, to be a general truth that there are comparatively few diamonds without cavities and flaws, and that this stone is a fouler stone than any other used in jewellery. Some diamonds, indeed, derive their black colour entirely from the number of cavities which they contain, and which will not permit any light to pass between them.

"Having found in diamonds so many pressure cavities, as we may call them, round which the substance of the stone is compressed, I had some expectation of finding them in other minerals; and in re-examining the numerous plates of topaz in my possession, I succeeded in discovering several under such remarkable circumstances that I submitted a description and drawings of them to this society in 1845. In searching for these phenomena with the polarizing microscope, we first observe four sectors of polarized light; and if the magnifying power is sufficient, we shall find in the centre of the black cross that separates the sectors a small opaque speck, which is the cavity or seat of the compressing force. This cavity is frequently of a rhomboidal form, and often only of the 3,000th or 4,000th of an inch in diameter. It is always opaque, as

if the elastic substance which it contained had collapsed into a black powder; and I have met with only one cavity in which there was a speck of light in its centre. The polarized tint of the luminous sectors varies from the faintest blue to yellow-green; blue and red tints of higher orders. In most cases the elastic force has spent itself in the compression of the topaz, the cavity remaining entire and without any apparent fissure, by which a gas or liquid could escape. I have discovered, however, other cavities, and these generally of a larger size, in which the sides have been rent by the elastic force, and fissures, from one to six in number, propagated to a small distance around them. These fissures have modified the doubly refracting structure produced by compression, but the gas or fluid which has escaped has left no solid matter on the faces of fracture."

The "Chemical News" gives, however, a brief commentary on the above, by stating that "Mr. Sorby finds that the supposed cavities in diamonds described by Brewster are, in reality, enclosed crystals; and the conclusion arrived at, from the consideration of the whole structure of the diamond, is not opposed to its having been formed at a high temperature. The crystals enclosed in diamonds are frequently seen to be surrounded by a series of fine radiating cracks, which are proved to be the result of the contraction suffered by the diamond in solidifying over the enclosed crystal; and this explanation has been artificially verified by examining crystals formed in fused globules of borax and glass cooled slowly, when the same phenomena are seen."

Compounds of Carbon with Oxygen.

Carbonic Acid or Carbonic Dioxide.—As all *acids* are now supposed to denote a salt of *hydrogen*, even the term "acid" when applied to carbonic acid would be incorrect, because the latter contains no hydrogen. Chemists, however, have met this difficulty by retaining a part of the name by which it is so well known, viz., carbonic, and adding thereto "anhydride," to show that it has no hydrogen.

Carbonic anhydride ($CO_2=44$; specific gravity, 1·529).—This gas, as already stated, is contained in atmospheric air, and is easily detected by exposing some lime-water in a dish to the air. A pellicle of carbonate of lime, calcic carbonate, or chalk, is formed, and therefore a compound of carbonic dioxide and calcium oxide.

This gas is easily obtained by acting on chalk, marble, limestone, oyster-shells, or whiting, by dilute nitric, hydrochloric, or sulphuric acids. Acetic acid (vinegar) may also be used.

The following equation is a simple example of decomposition:



$$\underset{\text{Chalk.}}{CaCO_3} + \underset{\text{Hydrochloric acid.}}{2HCl} = \underset{\text{Calcium chloride.}}{CaCl_2} + \underset{\text{Carbonic dioxide.}}{CO_2}$$

Calcium carbonate and hydrochloric acid give carbonic dioxide, water, and calcium chloride.

Carbonic dioxide has a slight acidulous odour, is colourless, transparent, and half as heavy again as atmospheric air. It was originally discovered by Dr. Black, who called it *fixed air*. It is perfectly unrespirable. If an attempt be made to breathe it, the epiglottis closes spasmodically, and suffocation occurs. It is a poison, and appears to act as a narcotic when mixed with

a large quantity of air, causing drowsiness, insensibility, and death; hence the danger of breathing an atmosphere contaminated with carbonic acid.

In sinking deep wells and pits the air may become foul from the breath of the workmen, or from other causes. The bad air, containing carbonic dioxide, is, however, soon removed by letting down a closed inverted umbrella, which, opening with a spring, is pulled quickly up and again lowered, until it is found that a candle will burn in every part of the pit or well.

When the air of a room contains $\frac{1}{10}$ per cent. of carbonic dioxide, it is no longer fit for respiration, and the bad effects of this dilute poison is shown by the fainting of delicate women, who are sometimes peculiarly sensitive to the action of this poison.

In the fermentation of beer large quantities of this gas are evolved; and many fatal accidents have been caused by the foolish carelessness of the brewers in entering vats too soon after the beer has been drawn off. The chokedamp of mines owes its life-destroying powers to the same cause—the presence of carbonic dioxide, which follows the explosion of fire-damp and air

It is an erroneous idea to suppose that carbonic dioxide, when once mixed with air, can separate itself and fall to the lower part of the room: it remains mixed by the law of diffusion, and the value of the law is thus seen to be very great; as it is quite possible to conceive that a separation might take place in a mechanical mixture of air and carbonic dioxide if this were not the case.

A solution of carbonic dioxide in water is called "soda-water," this beverage having derived its name, not from the gas which imparts the refreshing, sparkling character, but from the few grains of sodium carbonate added to the fluid contents of each bottle.

By a pressure of 38·5 atmospheres, and at a temperature of 32° F., carbonic anhydride is liquefied. It does not in this state dissolve freely in water; but if mixed with alcohol, ether, turpentine, or carbonic disulphide, solution occurs very rapidly, and this fact is taken advantage of to produce very low temperatures. When the liquid acid is allowed to escape from the apparatus devised and constructed by Mr. Robert Addams, the cold produced is so intense that the liquid acid solidifies in beautiful snow-like flakes, which may be collected in a proper box. If this solid carbonic dioxide is mixed with ether, the temperature sinks to—148° F. or 100° C., and if mercury is placed in the solution, it solidifies. A number of very pleasing experiments may be performed with solid carbonic dioxide, such as freezing water in a red-hot vessel. This experiment was originally performed by Faraday by placing some of the solid gas into a red-hot crucible, and, after pouring in a little ether, the mercury is quickly added, and in a few seconds assumes the solid state. Mercury freezes at a temperature of 40° below the freezing-point of water.

The ordinary gas is easily collected by displacement, and may be poured from one vessel to another. It extinguishes flame, and this test, with that of lime-water, enables the experimentalist to devise a number of amusing experiments, in which the breath, the gas from soda-water, or the combustion of charcoal or the diamond, are found to put out the light, and to change the lime-water milky white from the formation and precipitation of chalk. Carbonic dioxide gas may be drawn off by a syphon, or collected in a large jar and allowed to run out of a tap. If the jar is a wide-mouthed one, a child's india-rubber ball, or a balloon distended with air, will not sink in the gas, but remains floating, like a cork in water. 100 cubic inches of carbonic dioxide weigh 47·303 grains at 60° F., 30 in. bar.

A solution of the gas in water reddens blue litmus-paper, which is again restored to its original colour by boiling the paper in water, because the carbonic acid gas is driven off by the heat.

It is partly the carbonic dioxide dissolved by the rain which gradually filters through the strata, and dissolves the calcium carbonate and other matters found in spring-water. Carbonic dioxide is also produced in water by the oxidation of the organic matter by the oxygen of the air. Oxygen and organic matter in solution in water react upon one another, and carbonic dioxide is produced, whilst the oxygen originally dissolved in the water is reduced in quantity.

Various ingenious propositions have been made to enable persons to go with impunity into an atmosphere containing corbonic dioxide or other dangerous gases, or to attend on large voltaic batteries where nitrous fumes are evolved. The most practical and thoroughly useful contrivance is that of M. Galibert, and called by him the "Patent Respiratory Apparatus," being a most important



FIG. 489.—*Galibert's Apparatus.*

and valuable invention for the protection of life and property against danger arising from fire, also of persons exposed to danger from exhalations of gas, foul air in mines, sewers, &c., &c. It is simple, cheap, and effective.

This invention has been successfully introduced throughout the French empire, and the inventor has obtained many prizes and medals in acknowledgement of its merits.

A reservoir, of the capacity of five cubic feet, made of stout canvas, and

fireproof, is filled with air by means of a small bellows belonging to the apparatus, and placed on the back of the operator, as shown in the drawing, being suspended from braces passed over his shoulders, and further held in position by a belt round the body. There are india-rubber tubes, the two ends of which are inserted into the reservoir, the operator holding the other end in his mouth by means of a mouthpiece of horn to which they are attached, thus enabling him to breathe freely from the supply of air drawn through the tubes from the reservoir, without any inconvenience from dense smoke or poisonous gases.

The eyes of the operator are covered with goggles, so fitted as to effectually protect them from any gas or smoke, and the nostrils are closed by a small and simple instrument for that purpose.

The fire department of Paris has provided all its stations with the respiratory apparatus of M. Galibert. The city of Paris has adopted them, after experiments, for disinfecting sewers, &c.; the gas companies of Paris, and of all the large towns; the Transatlantic Steamship Company, many railway companies, the principal mining companies, and a great number of towns, for use in the fire departments, having adopted them after making decisive experiments.

These experiments have been described by the Counseil d'Hygiène et de Salubrité de Paris, by the Annales des Mines, et des Ponts et Chaussées, the "Moniteur," "Constitutionnel," "Presse," "Mondes," and all the journals of the cities and towns in which experiments with this invention have been made.

It has already been the means of saving nearly one hundred lives, and the inventor has received acknowledgments of its merits by numerous prizes and medals from public institutions. It is perfectly simple in its use, and the price is so low as to place one or more within the reach of all persons having property to protect.

The "Times," speaking of the invention, says,

"A very interesting and successful experiment was tried in Portsmouth Dockyard by M. Galibert, a Frenchman, the inventor of an apparatus to enable the wearer to breathe freely in the midst of the most dense smoke arising from a fire. Rear-Admiral Wellesley, Admiral Superintendent of the yard, the Hon. Captain Egerton, Captain W. Chamberlain, and the principal officers of the dockyard were present in the foundry, the drying-room of which was appropriated for the trial, and in which a quantity of straw, shavings, oakum, &c., had been placed, and which at three o'clock was ignited, the only aperture (the door) being then closed, so that the place was soon filled with a dense volume of smoke. M. Galibert then produced the apparatus, which consisted of a canvas bag, fireproof, which he inflated with air by a small pair of bellows; two gutta-percha tubes were affixed, at the end of which was a mouthpiece, which fitted to the teeth, the nostrils being at the same time closed by a small spring. The bag was then slung on his back. Being thus prepared, he entered the room, the door closed upon him, and there he remained eight minutes and fifty seconds, at the expiration of which time the door was opened, and he came out apparently without the slightest exhaustion; after which one of the police constables, John Lacy, No. 157, volunteered to try the experiment, which the admiral permitted, and being fully equipped and instructed by the inventor, he entered the room, where he remained three minutes—sufficiently long to test the utility of the apparatus. One of the labourers followed, and remained six minutes, and both men stated that they found no inconvenience

while in—they could breathe as freely as in the open air, and could have remained any length of time. Subsequently a ladle was heated, in which a quantity of sulphur was put, thus rendering the smoke still more dense; but M. Galibert, after being in six minutes, returned again without the slightest inconvenience. The thermometer was at 91°."

Carbonic Oxide.

Carbonic Oxide (symbol, CO; atomic weight, 28).—When carbonic dioxide is passed through red-hot charcoal, it parts with one atom of oxygen, which unites with another of carbon to form carbonic oxide.



$$\underset{\text{Carbonic acid.}}{CO_2} + \underset{\text{Carbon.}}{C} = \underset{\text{Carbonic oxide.}}{2CO}$$

This gas is even more poisonous and insidious than carbonic acid, and is produced in considerable quantities during the burning of bricks, where the conditions are favourable for the passage of carbonic acid gas through red-hot charcoal (the cinders called "breeze") with which the bricks are burnt.

By boiling crystals of oxalic acid with strong sulphuric acid, the former is decomposed into carbonic acid and carbonic oxide (CO_2 and CO), the elements (H_2O) which form water being removed by the sulphuric acid.

Carbonic oxide burns with a lambent blue flame, and is converted into carbonic acid. The former is lighter than the latter, and has a specific gravity of 0·967.

Compounds of Carbon with Hydrogen.

To the department of organic chemistry belongs the most numerous portion of the hydro-carbons. There are, however, two compounds of carbon and hydrogen which deserve special notice here:

Light carburetted hydrogen (CH_4); Heavy carburetted hydrogen (C_2H_4).

Marsh gas—firedamp—light carburetted hydrogen, methyl hydride (CH_4)—so dangerous in coal-mines because the gas does not possess any odour to warn the miner of its presence—has no colour or taste, and is evolved from stagnant pools and ditches where dead leaves accumulate and decompose.

Soda and sodium acetate heated together yield sodium carbonate and light carburetted hydrogen gas.

Olefiant gas—heavy carburetted hydrogen, ethylene (C_2H_4)—is an important constituent of coal-gas, to which it imparts its chief illuminating powers. Methyl hydride burns with a bluish-yellow flame, whilst olefiant gas burns with a luminous and somewhat smoky flame, betraying the excess of carbon it contains; in fact, this gas contains twice as much carbon as marsh gas united with the same molecule of hydrogen. It is prepared by carefully heating one part of alcohol with five of sulphuric acid: the elements of water are removed by the latter, and olefiant gas (C_2H_4) evolved. It is called olefiant from the Latin *oleum*, oil, and *fio*, to make; because the associated Dutch chemists, Brandt, Dieman, Troostwick, and Laurenberg, in the year 1796, found that when it was mixed with chlorine gas, a peculiar liquid resembling a heavy oil was produced.

Both of these hydro-carbon gases are contained in coal-gas, with other compounds of carbon, and various impurities which it is the duty of the "gas-works" to remove before the gas is supplied to the consumer. But the consideration of such an important theme as coal-gas would demand more space than the limits of this work will permit.

BORON.

Symbol, B. Atomic weight, 10·9.

Sir Humphrey Davy proved this to be an element, and the base of boracic acid, in the year 1807. Boracic acid is obtained from borax, so called from the Arabic *buruk*, which signifies *brilliant*.

Wohler and Deville give the following directions for the preparation of amorphous, dull, olive-green boron in the state of powder: 150 grammes of fused boracic anhydride (boracic acid, B_2O_3), are coarsely powdered and mixed rapidly with 90 grammes of sodium cut into small pieces. The mixture is then introduced into a cast iron crucible previously heated to bright redness; 70 or 80 grammes of solid and previously fused sodium chloride are placed upon the top of the mixture, and the crucible is covered. As soon as the reaction is over, the still liquid mass is thoroughly stirred with an iron rod, and poured whilst red hot in a slender stream into a large and deep vessel containing water acidulated with hydrochloric acid. The pulverulent boron is then collected on a filter, and washed with acidulated water till the boracic acid is got rid of; after which the washing may be continued with pure water until the boron begins to run through the filter. It is finally dried upon a porous slab without the application of heat.

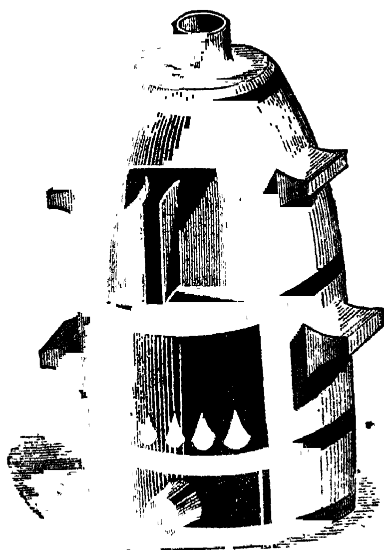


FIG. 490.
Useful Furnace for Crucible operations.

Crystallized Boron. — In order to convert the amorphous into the crystallized form, the same chemists adopt the following method:

"A small Hessian crucible is lined with the powder or amorphous boron, made into a paste with water, the boron being pressed in strongly, as in the ordinary mode of lining a crucible with charcoal. In the central cavity a piece of aluminium, weighing from 6 to 9 grammes, is placed; the cover is luted on, and the crucible enclosed in a second, the interval between the two being lined with recently ignited charcoal. The outer crucible is next closed with a luted cover, and the whole exposed for a couple of hours to a heat sufficient to melt nickel; the temperature is then allowed to fall, and when cold the contents of the inner crucible are digested in diluted hydrochloric acid, which dissolves out the aluminium; beautiful crystals of boron are left, generally transparent, but of a dark brown colour.

A quantity of *scales* of the so-called graphitoid boron—an alloy of boron with aluminium (B_2Al)—are formed at the same time in pale copper-coloured opaque plates.

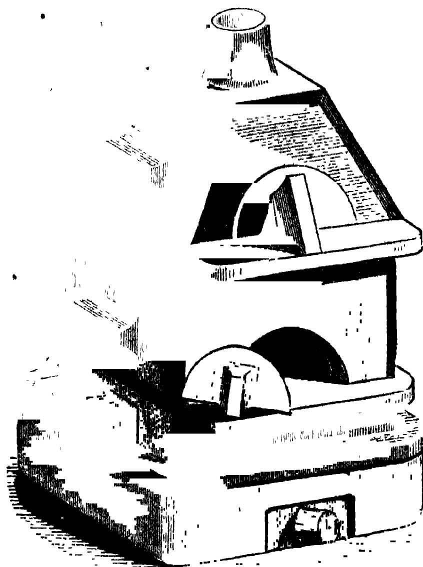


FIG. 491.—*Strong Fire-clay Furnace.*

Boron, like carbon and silica, exists in three conditions, viz., amorphous, crystalline, and graphitoidal. Crystallized boron has a specific gravity of 2·68, and Deville exhibited crystals of the octohedral form hard enough to scratch the ruby. In the remarks on silicon reference will be made to the manufacture of artificial precious stones.

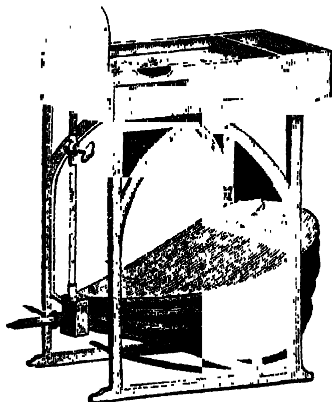


FIG. 492.—*Forge, Bellows, and Iron Tray*;
For small operations where an intense heat is required.

The most important compound of boron and oxygen is boracic trioxide, (boracic acid, B_2O_3.) It is obtained from the volcanic districts of Tuscany, which puff out jets of steam and gas: they contain small quantities of boracic acid, and are condensed and dissolved in the small lakes and lagoons surrounding the mouth of the jets. The very weak solution thus naturally formed would involve great expense for coal or other fuel if evaporated in the ordinary way; but Nature gives with the weak solution of boracic acid natural steam-jets, and these are used to evaporate the water of the

lagoons. From borax ($Na_2B_4O_7$) boracic acid is procured by dissolving four parts of pure borax in boiling water, and then adding sulphuric acid equivalent to one-fourth of the weight of the borax. Sodic sulphate is formed, and bo-



FIG. 493.—*Gas-burner, and Platinum Crucible and Crucible Jacket,*
For fusing bodies not requiring a high temperature.

racic acid crystallizes out on cooling in pearly-looking scales: these are washed with ice-cold water, dried, and fused in a platinum crucible. The fused crystals are then re-dissolved in four times their weight of boiling water, and the boracic acid crystallizes on cooling in a state of purity.

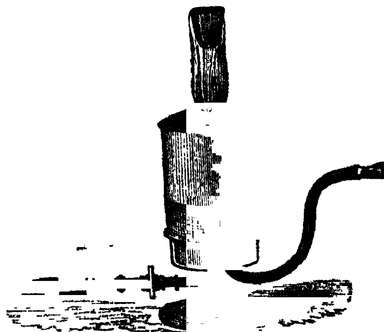


FIG. 494.—*Dr. Normandy's Mixed Air and Gas-burner,*
With a blowpipe jet in centre to urge flame on crucible.

There is a trifluoride of boron (BF_3) and a boric nitride or nitride of boron (BN), for boron possesses the remarkable property of combining with nitrogen at a red heat.

SILICON.

Symbol, Si. Atomic weight, 28.

A non-metallic substance (at present), whose existence in flint (*silex*) was suspected by Sir H. Davy, silicon, like boron, may exist without form, *i.e.*, amorphous; as, for instance, when obtained by passing the tetra-fluoride of

silica into water, producing an acid solution. The tetra-fluoride is obtained by heating a mixture of sand with powdered fluor spar and sulphuric acid. The gas must be passed through a cup containing mercury, or the deposited silica hydrate ($H_2OS_1O_2$) would soon close the tube, and, stopping the further exit of the gas, would cause an explosion to take place.

The acid liquor neutralized with a solution of caustic potash yields potassic silica fluoride (2KF, Si_4F).

When this salt is dried and mixed with nearly its own weight of sodium, and heated in a glass tube, sodium fluoride is formed, whilst silicon is reduced; and when the whole is thoroughly washed, collected, and dried, a dull brown powder is obtained.

Silicon, like carbon and boron, may be obtained in three conditions—amorphous, graphitic, and crystalline. In the amorphous state it can be burnt in oxygen, and then forms silica. Crystals of silica are obtained by putting into a red-hot crucible a mixture of three parts of potassic silica fluoride with one of metallic sodium and four of zinc: of course the perfection of manipulation requires that the sodium shall be minced and the zinc granulated. When cool, the crystals deposited on the zinc are found to be silica, which can be separated from the former by hydrochloric acid, and subsequently by boiling nitric acid. Silica thus obtained will scratch glass, and has a specific gravity of 2·49.

The graphitic form of silica is obtained by heating the amorphous silica at a high temperature.

The compound of oxygen and silica which specially demands consideration is silicic dioxide or silica—the substance which, next to oxygen, is the most abundant in nature. It not only exists as silicic dioxide, nearly pure, as a mineral (SiO_2=60), but is abundantly distributed in the form of silicates through the mineral productions of the known crust of our globe. Primary rocks owe their hardness chiefly to the presence of silicic dioxide.

Silica occurs in two states—amorphous when prepared by passing the tetrafluoride of silica into water, as already described. The deposited silica may be washed, dried, and heated to a great heat, and then appears perfectly snow-white.

Common flint stones, heated red hot and plunged into water, afford a white powder which is nearly pure silica. Any artificial amorphous form of silica is easily dissolved in alkaline solvents, hence the manufacture of water-glass.

The crystalline forms of silica quartz are legion. "Quartz is composed of pure silica, generally combined with minute proportions of metallic oxides, from whence the varied and brilliant colours it frequently exhibits are derived. It is a most abundant mineral, forming extensive veins and masses in primitive and transition rocks, and consequently is diffused over almost every quarter of the globe. It is an essential constituent of granite, gneiss, mica-slate, and other allied rocks, and in the form of sand forms nearly the whole of the mobile soil of the sterile desert. In South America quartz has been observed by Humboldt in mountain masses or beds, many hundred feet in thickness." Its specific gravity varies from 2·5 to 2·8, and is 2·65 in the purer varieties.

"Quartz consists of many varieties, differing much in external appearance, all of which readily scratch glass, and equal 7 in Prof. Moh's scale of hardness. It is infusible *per se* before the blowpipe, but with soda fuses with intumescence into a transparent glass, and is insoluble in all acids excepting hydro-fluoric acid: when pulverized it is slightly soluble in a solution of caustic potash.

Quartz occurs massive and crystalline, also fibrous, stalactite, granular, spongiform, pseudo-morphous, &c." *

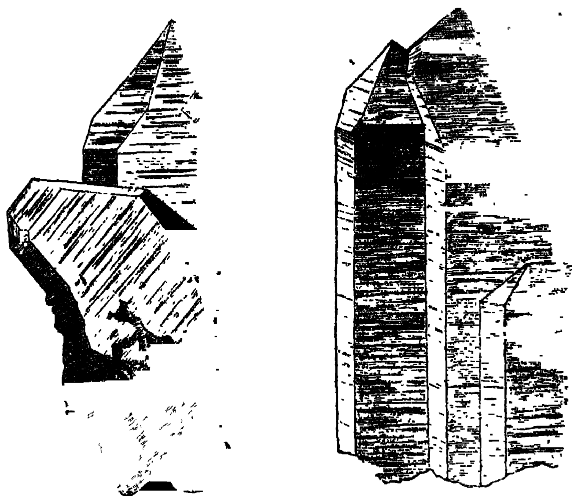
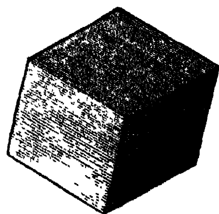


FIG. 495.—*Single Crystal of Quartz.* FIG. 496.—*Group of Crystals of Quartz.*

The following are the names used by mineralogists for crystallized quartz: Rock crystal. Dragonite. Quartz, *Phillips Brook and Miller, &c.*; Quartz *Hauy Naumann, Werner, Haidinger, Hausmann.* Rhombohedral Quartz, *Moh's.* Whitestone of the jewellers. Berg crystal.

Silica . .	99·37
Alumina .	trace
	99·37 Bucholz.
Specific gravity	2·653 Bendant.



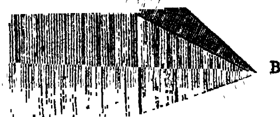


FIG. 497.
A, Primary form of crystal; B, the usual form, hexagonal prism, terminated by hexagonal pyramids.

There is a remarkable combination of silicon and hydrogen (H_4Si) called siliciuretted hydrogen, which, like phosphuretted hydrogen, takes fire spon-

* "Elementary Treatise on Quartz and Opal." By S. W. Traill, F.G.S.

taneously in the air, forming silica and water. A silicic nitride, sulphide, chloride, and fluoride are also amongst the carefully recorded compounds of silica.

The "Literary and National Gazette" thus describes the manufacture of gems, and the colouring and improving of stones belonging to the quartz class.

How Gems are Manufactured.

"That many things glitter which are not gold is well known; but do the wearers of jewellery know that the bright and beautiful colours exhibited by most of their much-prized gems are purely artificial? Nature supplies the raw material, and art steps in to embellish it. The brilliant necklace or bracelet, which, with the native hue of the stone, would by no means be considered ornamental, becomes matchless in tint and lustre after passing through the hands of the artificer. Your chemist, always discovering something and always ready with marvellous transformations, is truly a remarkable personage. He is jealous of his secrets, but not always able to keep them. If he could set a seal on his doings, our readers would not have been entertained with the present article, in which we shall take leave to reveal some of his processes.

"Let us begin with agate—rather a common stone, found almost everywhere, and in numerous varieties, among which are the chalcedony, cornelian, onyx, sardonyx, and heliotrope. They all consist principally of quartz, and are more or less pellucid. In some places they are surprisingly abundant. One of these places is Oberstein, some thirty or forty miles up the valley of the Nahe, a region not often visited by summer tourists, yet interesting enough to repay him who shall explore its devious byways and paths along the river. At the village just mentioned, and at Idal, four miles distant, formations of coarse red conglomerate are met with, interposed with trap and greenstone; and in soft strata in these rocks agates are found in considerable quantities. The workings may, indeed, be called agate-quarries, for they are carried on in the precipitous side of a hill; and to him who sees them for the first time there is something remarkable in the species of industry created by the presence of the stones.

"The nodules of agate, as they come from their long-undisturbed bed, are generally of an ashen-grey colour. The first operation in the process of transformation is to wash them perfectly clean; then to put them into a vessel containing a mixture of honey and water, which, being closely covered, is plunged into hot ashes for two or three weeks. The essential thing is to keep the liquid from boiling, but at a high temperature. After a sufficient interval the stones are taken out, cleansed, passed through a bath of sulphuric acid, and then they undergo a second course of roasting in the hot ashes.

"To produce a colour in the stones, it is necessary they should be penetrated by some carbonizable substance. This is effected by the honey, which, under the influence of long-continued heat, finds its way into the interior of the crystal, where its carbonization, if not complete in the first instance, is finished by the sulphuric acid. Some lapidaries use olive oil instead of honey. The shade of colour depends on the porosity of the layers of the stone: the most porous become at times perfectly black. Some are coloured in two or three hours, others in as many days, others in a week or two, and some resist all attempts to change their natural hue. Some, when they are taken out of the pan, are found to be a rich dark brown, or chocolate; others, again, having

been penetrated by the colouring matter between the layers, are striped alternately white, grey, and brown, like the onyx and sardonyx.

"By soaking the stones in a solution of sulphate of iron, and then placing them for a few hours in the oven, a fine cornelian red is produced in the porous layers, while those not porous remain unaltered. Thus it not unfrequently happens that very coarse and common stones—muddy yellow or cloudy grey —which in their natural condition would be valueless, are passed off as stones of the first quality. It is only within the last forty years that this process has been known in Germany; but the Italian lapidaries were acquainted with it centuries ago. Hence we can account for the exquisite colour of antique cameos and other ornaments once numerous in the cabinets of Italy, and now to be seen in museums and private collections in all parts of the world.

"The dealers, when making their purchases of what we may call the raw material, select what appears to be a desirable piece, and chipping off a minute portion, they moisten the exposed surface with the tongue, and watch the absorption of the moisture. If regular and equal, the stone is good for an onyx; if not, it is added to the heap of inferior varieties. This, however, is but a rough-and-ready test, and not always decisive.

"The pores of the stones by which the colour is conveyed and retained are visible with the microscope, and the effect of various tints is produced according as the light falls upon them at different angles. The rainbow agate is full of minute cells, which, when exposed to the sun, produce prismatic colours, as is observed of the striæ of mother-of-pearl. To detect cavities in the stones, they are soaked in water, which, slowly penetrating, reveals the hollows. Some already contain water when first found; and it is a remarkable fact that, if kept in a dry place, the water disappears, but without leaving the slightest traces of moisture on the surface, and the stones can only be refilled by boiling them.

"Balls of striped red chalcedony are much prized: a large one weighing 100 lb. was found in 1844 near Weisselberg, and was sold in the rough for 700 guelders. Some kinds of chalcedony are made to appear of a citron yellow, by a two days' roasting in an oven, and a subsequent immersion in a close hot bath of spirits of salt for two or three weeks. A blue colour, which has all the effect of a torquoise, is also produced, but the particular colouring process has hitherto been kept a secret. These stones which are naturally coloured are at times roasted, to heighten the tint and add to its permanency. The Brazilian cornelian becomes singularly lustrous under the process; the explanation being that the long-continued action of heat removes the oxhydrate of iron contained in the stone, leaving it with a clear brightness diffused through the whole mass. The smallest stones are roasted before polishing, but the large ones, of which saucers, vases, cups, plates, &c., are made, are first cut into the required shape and thinness—otherwise they fly to pieces when exposed to heat. After all the colouring operations have been gone through, the stones are ground on a wheel soaked in oil for a day, to conceal the fine scratches and give a good polish, and then cleaned off with bran.

"Those who examined the collection of gems and works of art from rare stones in the Great Exhibition of 1851, will remember the elegant onyx vases of different colours—some streaked with white natural veins; the cups of red chalcedony; a chain of the same substance in large square links of different colours and without visible joints; besides other objects so beautifully finished that a prize medal was awarded to the manufacturers.

"So far we have been treating of methods by which Art assists Nature: we come now to the gems that are not found in the side of a quarry, but formed in the chemist's laboratory. Before the days of Berlin wool and crochet-work, young ladies used to amuse themselves by making crystalline baskets and trays, as ornaments for the mantelpiece; but they had first to dissolve their alum. The chemist works by other means, and, especially since the application of electro-galvanism to his processes, there is something really wonderful in the results. He produces crystals at pleasure, and in lumps that would astonish those who once laboured so hard in search of the Philosopher's Stone. A few years ago M. Ebelmas laid before the French Academy of Sciences specimens of artificial quartz– some white, others blue, red, and violet; and by mixing chloride of gold with the silicic acid used in the composition, he produced a mass traversed throughout with delicate veins of gold, similar to the lumps brought from Australia and California. By a modification of his process he produced hydrophane—that species of opal which is transparent only when immersed in water—and specimens also of the allied crystal, hyalite. In this operation silicic ether and moist air are principally employed; and a variety of colours could be imparted by the admixture of different coloured alcoholic solutions. Chloride of gold produces a beautiful topaz yellow; and by exposing the crystal for a time to light, the gold is dispersed through it in flakes, as an aventurine; and kept in sunlight, the flakes change to a violet or rose-colour, and become transparent. In this fact we have an extraordinary instance of molecular action—the distribution of metallic scales through a solid mass; one which, as some geologists suppose, helps to throw light on the mode of formation of rocks and minerals. That pieces of wood, plants, and animal substances will become silicified, or, as is commonly said, petrified, is well known; and though often wondered at, the diffusion of the gold flakes through the crystal is yet more marvellous."

SELENIUM.

Symbol, Se. Atomic weight, 79·5.

This element is intimately connected with, and allied to, sulphur, and was discovered by Berzelius, in 1817, in the refuse of a sulphuric acid manufactory at Gripsholm, near Fahlun, in Sweden. It has been found in the natural state at Culebras, in Mexico.

The vitreous form of the element, obtained by melting this substance, is well shown in the medallion portraits of Berzelius, which used formerly to be very common, and are cast in selenium (Fig. 498). When selenium is dissolved in carbonic disulphide and deposited from this solution, it assumes the crystalline form. There is evidently a change in density when selenium is crystallized, because the element in the fused or vitreous state has a specific gravity of 4·500, and 4·700 in the crystalline form; moreover, the latter melts at a temperature of 217° F., whilst the former softens at a heat a little above the boiling-point of water. Dr. Miller says the statements regarding the point of fusion of selenium are discordant, owing to its power of existing, like sulphur, in several distinct modifications. It has neither taste nor smell, and when examined by transmitted light, in a finely-divided state, has a red colour.

Fused selenium forms a solid of a deep brown colour, with a glassy fracture

and metallic lustre. It is insoluble in water, and is a non-conductor of heat and electricity. It burns in the air with a bright blue flame, emitting a peculiar odour.



FIG. 498.—*Portrait of Berzelius, the Discoverer of Selenium.*
(From a cast in that substance)

The compounds of oxygen and selenium are selenic dioxide, or selenious anhydride (SeO_2), selenic trioxide (SeO_3),—the latter has not yet been isolated, although the acid and salts corresponding with it are known,—selenic acid, or dihydric selenate (H_2SeO_4). There are consequently *selenites* and *seleniates*.

Seleniuretted hydrogen, or dihydric selenide (H_2Se), is prepared by the action of an acid on a selenide, and gas is obtained which painfully stimulates the nose, destroying for some hours the sense of smell; indeed, a very small bubble of the gas let into the nostrils of the operator deprives him, says Griffiths, so completely of the sense of smell, that he cannot discover even the extremely pungent odour of ammonaical gas. This compound corresponds in its properties with that nauseous-smelling gas called sulphuretted hydrogen.

There are two compounds of selenium and chlorine, Se_2Cl_2 and $SeCl_4$; the former is a brown volatile fluid, and the latter a volatile white crystalline mass.

SULPHUR.

Symbol, S. Atomic weight, 32.

The greater quantity of sulphur used in England comes from the volcanic regions of Sicily, near the base of Mount Etna, and in other places on the borders of the Mediterranean. The native sulphur is purified by sublimation, and the apparatus employed is shown at Fig. 499, and is thus described by Muspratt:

"In 1815 a manufacturer named Michel, of Marseilles, devised an apparatus which, with some slight modification, is in use up to the present day. Fig. 499 represents the retort wherein the sulphur is converted into vapour, and a condensing-chamber into which this is converted into solid sulphur. The apparatus, as in the drawing, consists first of a retort, C, beneath which is a furnace, A: this retort is filled with liquid sulphur from the reservoir, B,

wherein the crude sulphur is melted by the waste heat of the furnace to facilitate its introduction into the retort. When the retort has become sufficiently hot, the sulphur begins to pass as vapour through the tube or opening D into the condensing-chamber, E. This chamber is built entirely of brick, with a well-cemented brick floor. On its upper part a small chimney is erected; this chimney contains a small wooden valve or door, capable of opening outwards to allow the expanded air to escape, and, in case of explosion, to allow the gases produced immediate exit. This apparatus, when cold, allows solid sulphur to form at once in the shape of the ordinary commercial flowers of sulphur; the vapours immediately coming in contact with the cold chambers

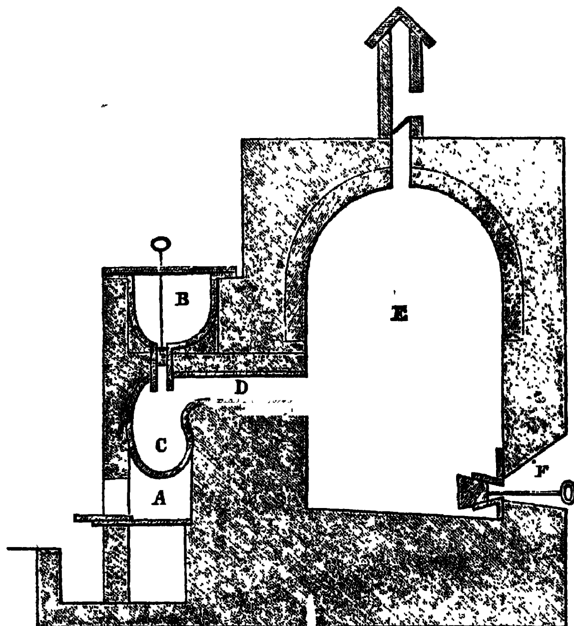


FIG. 499.—*The Subliming Apparatus used in the purification of crude Sulphur.*

are chilled, and fall as a minutely-divided solid. These flowers, as they are called, are removed before the chamber gets hot, which is the case after a few days' working. The whole of the heat which the sulphur has taken up in order to become vapour being given out to the walls, they thus acquire such a high temperature as to fuse sulphur; therefore it can no longer become solid, but condenses on their surface in a liquid form, and falls down to the bottom, where it collects. When the operator is satisfied that sufficient has distilled over, he proceeds to remove it; this he does by the plug apparatus, F, which is only an iron plug with a long handle, and by pushing the plug inwards he opens the passage for the flow of liquid sulphur, which runs into suitable moulds to form the sticks or rolls of commerce. The residue is raked out of the retort, which

is immediately charged again by removing the plug that closes the tube between the vessel B and the retort."

Native sulphur occurs in the amorphous and crystalline states. When pure, sulphur is insoluble in water, tasteless, but emits a peculiar odour. It is very inflammable, and takes fire at a temperature between 450° and 500° F., producing the pungent and very suffocating gas called sulphurous anhydride (SO_2).

Although chiefly used in the manufacture of oil of vitriol, sulphur is employed extensively in the manufacture of lucifer matches, and is an important constituent of gunpowder. It is also used for bleaching silk, flannel, feathers, &c.

There are three modifications of sulphur: first, the natural crystals, the octohedron with a rhombic base, and two other allotropic conditions, viz., one obtained by melting and crystallizing sulphur in needles, and the third a red amorphous substance, obtained by pouring melted sulphur into water.

The compounds of sulphur with oxygen are two in number:

Sulphurous anhydride . . .	$SO_2 = 64$.
Sulphuric anhydride . . .	$SO_3 = 80$.

The oxyacids of sulphur are very numerous:

Sulphurous acid	$H_2SO_3 = 82$.
Sulphuric acid	$H_2SO_4 = 98$.
Hyposulphurous acid . .	$H_2S_2H_2O_4 = 132$.
Dithionic acid	$H_2S_2O_6 = 162$.
Trithionic acid	$H_2S_3O_6 = 194$.
Tetrathionic acid	$H_2S_4O_6 = 226$.
Pentathionic acid	$H_2S_5O_6 = 258$.

Sulphurous anhydride, or sulphuric dioxide (symbol SO_2, atomic weight 64), are the scientific names of the pungent suffocating fumes given off when sulphur is burnt. It is easily prepared by boiling 2 oz. of quicksilver with 3 oz. of sulphuric acid; the former deprives the latter of a portion of its oxygen. The reaction that takes place is shown in the following equation:



$$Hg + 2H_2SO_4 = HgSO_4 + SO_2 + 2H_2O$$

Mercury. + Oil of vitriol. = Sulphate of mercury. + Sulphurous anhydride. + Water.

Copper may be used instead of mercury, but when a small quantity of sulphurous anhydride is required, the evolution of the gas is much quicker with the latter metal.

Sulphurous dioxide has a specific gravity of 2·247, and therefore is easily collected by displacement or over mercury in the mercurial trough. The gas should be washed by allowing it to bubble through a little water placed in a Woolfe's bottle.

Sulphurous dioxide has no colour, and cannot be respired. When subjected to a temperature of —10° F., by means of a freezing mixture of snow and salt, it is reduced to the liquid state at the ordinary pressure of the air.

After collecting the liquid gas in a strong tube, the latter may be hermetically sealed, and when the temperature rises to 60° F. the liquefied gas exerts a pressure of more than $2\frac{1}{3}$ atmospheres, viz., 2·54.

The liquid gas cooled below —105° F. freezes to a crystalline solid.

Sulphurous anhydride combines with water, and is then termed sulphurous acid, H_2SO_3. Water dissolves 68·8 times its bulk of sulphurous anhydride at a temperature of 32° F. The solution is used now for certain throat diseases in the form of fine spray, and is a great boon to public singers or speakers,

and in some cases the cure effected is almost magical in rapidity. The acid is a powerful antiseptic and anti-putrescent body. It stops the ordinary fermentation of sugar, and is one of the best disinfectants that can be used. Sulphur burnt in the air will afford sulphurous anhydride sufficiently good for this purpose. Unlike chlorine, it is used as a deoxidizing agent for bleaching silk, flannel, isinglass, feathers, sponge, straw, &c. Sulphurous anhydride is not an inflammable gas, and will not support the combustion of a burning taper.

Sulphuric acid (dihydric sulphate, $H_2SO_4=98$) is the most important acid used in commercial chemical processes. One hundred thousand tons are made and used annually in this country.

The chief importance of the gas already considered, viz., sulphurous anhydride, is due to the fact that it is the starting-point in the manufacture of oil of vitriol. The gas, by a most ingenious process, is made to combine with half as much oxygen again as it already contained; and, what is still cleverer, the oxygen is obtained for nothing, because it is taken from the great reservoir of oxygen, viz., the air. Sulphurous anhydride and oxygen, both dry, when passed over spongy platinum heated in a tube, combine, and sulphuric anhydride (SO_3) is produced. It is called by some authors sulphuric trioxide. Curious to state, this body does not redden litmus or blacken the skin. It combines with water with great rapidity, and, when brought in contact with the latter fluid, hisses like a red-hot iron, forming sulphuric acid, H_2SO_4.

In the commercial process sulphurous anhydride (SO_2) is oxidized in a capacious leaden chamber by the intervention of another gas (nitric oxide), with the assistance of moist air. Nitric oxide in contact with the air produces the red fumes of nitric trioxide (N_2O_3) which yields oxygen to the sulphurous anhydride, and converts it into sulphuric acid. The decomposition is thus tersely described by Roscoe:

"$SO_2+H_2O+N_2O_3=H_2SO_4+N_2O_2$—sulphuric dioxide, water, and nitric trioxide—yield sulphuric acid and nitric oxide. The nitric oxide formed in this decomposition takes up another atom of oxygen *from the air*, becoming N_2O_3, and this is again able to convert a second molecule of SO_2 with H_2O into H_2SO_4, being a second time reduced to N_2O_2, and ready again to take up another atom of oxygen *from the air*. Hence it is clear that N_2O_2 acts simply as a carrier of oxygen between the air and SO_2; an indefinitely small quantity of this nitric trioxide being, therefore, theoretically able to convert an indefinitely large quantity of sulphurous dioxide, water, and oxygen into sulphuric acid."

Protohydrate of sulphuric acid (the oil of vitriol of commerce), H_2SO_4, is a dense oily-looking fluid, having a specific gravity of 1·842. It blackens organic matter, and when mixed with water becomes very hot: the volume of acid and water is found to be reduced in bulk when cold.

Sulphuric acid boils at a temperature of 620° F., emitting a dense white vapour, and it distils without decomposition. Some pieces of platinum foil should be placed in the bottom of a distilling vessel to prevent the violent and explosive formation of the acid vapour.

If a little sulphuric acid is placed in a beaker up to a certain mark, it will be found in the course of a day or so to have risen above the mark, in consequence of the absorption of the watery vapour contained in the air. Organic substance, and especially sugar, is completely decomposed and charred when oil of vitriol is poured upon it. This acid has little or no action on metals in

the cold state, but when some of the latter are boiled in sulphuric acid, sulphates are obtained.

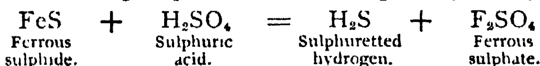
In the practice of the art of photography (see p. 574), large quantities of sodium hyposulphate are used. The latter salt is obtained by passing a current of sulphuric dioxide into a solution of sodium sulphide; the resulting hyposulphide is purified by crystallization. Hyposulphurous acid, or dithionous acid ($H_2S_2H_2O_4 = 132$), forms with sodium a salt in which one of the molecules of hydrogen is replaced by that of sodium, viz., $Na_2H.S_2O_4$. A solution of this salt possesses the property of dissolving out the silver compound (iodide or chloride, as the case may be) which remains unaltered by light; whilst those portions of the silver compounds reduced to the metallic state by the action of light are not affected by this salt, which is therefore said to fix the photographic picture. Hyposulphurous acid is only known in combination, and has not yet been isolated.

Compounds of Sulphur with Hydrogen.

Hydrosulphuric acid; sulphuretted hydrogen; dihydric sulphide, $H_2S = 34$. This gas was discovered by Scheele in the year 1774, and it is usually obtained from ferrous sulphide (FeS) by the action of dilute sulphuric acid.

To prepare the ferrous sulphide, some clean iron turnings or small coils of iron wire are to be placed in a covered crucible banked up with hot coke on the stage of the forge bellows (p. 588). The blast should then be urged until the crucible has attained a bright red heat, when the cover of the crucible may be raised, and fragments of sulphur dropped in. The action is very apparent, as the iron glows with a still more intense heat in the act of combining with the sulphur, and if the operation is nicely performed, the whole assumes the liquid state, and may be poured into a mould or allowed to cool in the crucible.

Ferrous sulphide, by decomposition with sulphuric acid, yields sulphuretted hydrogen; the iron being displaced from the sulphur by the hydrogen.



$$\underset{\text{Ferrous sulphide.}}{FeS} + \underset{\text{Sulphuric acid.}}{H_2SO_4} = \underset{\text{Sulphuretted hydrogen.}}{H_2S} + \underset{\text{Ferrous sulphate.}}{F_2SO_4}$$

The sulphide of iron is placed in the bottle A, and sufficient water is poured upon it through the funnel B. A little sulphuric acid is now added, and the gas passes through the tube C, connected with E by a piece of vulcanized india-rubber tube. Here the gas is absorbed by distilled water in F, and if required pure, again escapes, when the latter is saturated through G by H and J into the beaker glass, K, containing more distilled water, or any fluid, such as a solution of lead or arsenic, whose presence it may be desirable to determine.

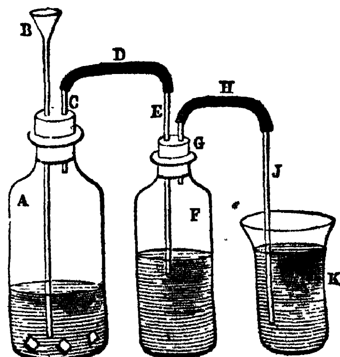


Fig. 500.—*Preparation of Sulphuretted Hydrogen.*

Water at 59° F. dissolves 3·23 times its bulk of sulphuretted hydrogen. The solution has a slight acid reaction, and, of course, the smell of the gas, which reminds the nose of the odour of putrid eggs. This gas, which consists of two volumes of hydrogen and one

volume of sulphur vapour condensed into two volumes, has a specific gravity of 1·191; and 100 cubic in. weigh, at 60° F. and 30 in. bar., 38 grains. It is very poisonous, and if one measure is mixed with 600 or 1,200 measures of air, the highly diluted gas is still most poisonous and will soon cause the death of a mouse or a bird.

The analytical chemist requires this gas for the purpose of determining in a qualitative analysis the particular group to which any metal discoverable by this gas may be referred, and it is one of the most useful re-agents employed in the laboratory.

There is another compound of sulphur and hydrogen called hydric persulphide, or persulphide of hydrogen, H_2S_2.

Sulphur also unites with carbon, forming a most useful and volatile fluid called carbonic bisulphide or bisulphide of carbon, $CS_2 = 76$. This compound dissolves phosphorus in the ordinary state, but not when in the amorphous condition. It is one of the best solvents of caoutchouc, gums, sulphur, &c.

Sulphur chloride ($S_2Cl_2 = 135$), sulphur dichloride ($SCl_2 = 103$), and nitrogen sulphide (SN) complete the list of sulphur compounds.

PHOSPHORUS.

Symbol, P. Atomic weight, 31.

A merchant of Hamburgh, engaged in the useless attempt to obtain the Philosopher's Stone exactly 200 years ago, viz., in the year 1669, discovered accidentally this peculiar substance. The name of this clever and persevering chemist was Brandt, who described the phosphorus he obtained as a "dark, unctuous, daubing mass." There are many other interesting particulars respecting the history of the discovery of this substance that will be found in a most exhaustive pamphlet by Mr. George Gore,* from which the following is taken:

"In a 'Historical Sketch of the Progress of Pharmacy in Great Britain, by Jacob Bell,' it is stated, that 'A house and shop, with a laboratory, were built on the Bedford estate, in the year 1706, by Ambrose Godfrey Hanckwitz, who had carried on business as a chemist in the neighbourhood since 1680. He was a maker of phosphorus and other chemicals, which were rare at that period, and which he sold in different parts of the country during his travels. His laboratory was a fashionable resort in the afternoon on certain occasions, when he performed popular experiments for the amusement of his friends. It opened with glass doors into a garden, which extended as far as the Strand, but which is now built upon. Four curious old prints of the laboratory in its former state are in the possession of its present proprietors, Messrs. Godfrey and Cooke, of Southampton Street, Covent Garden, also a portrait of Ambrose Godfrey Hanckwitz, engraved by George Vertue (1718), which he had distributed among his customers as a keepsake.'

"When we consider that 1,000 parts of urine contain scarcely one part of phosphorus, and of this probably only a portion was obtainable by the processes first in use, we shall not be surprised at the statement of Boyle that 'the liquor yields but a small proportion of the desired quintessence,' or at the price of 50*s*.

* "On the Origin and Progress of the Phosphorus and Match Manufactures." By G. Gore.

an ounce charged by Hanckwitz for his product. Even an improved process, purchased and published by the French Government in 1737, yielded, under the direction of Hellot, Geoffroi, Dufay, and Duhamel, only four ounces of phosphorus for every five hogsheads of the liquid.

After the death of Hanckwitz, in 1741, some experiments were made by Margraaf, Fourcroy, Vauquelin, and others; but no great improvement in the production of phosphorus appears to have been effected until 1769, when Gahn made the important discovery of phosphoric acid in bones. Margraaf had already demonstrated the individuality of this acid as early as the year 1740, and it only now remained to devise a process for extracting it. Scheele immediately did this, and various eminent chemists quickly succeeded in making various improvements in the method of working, and bequeathed unto us substantially the same process of manufacture as that now in operation.

"The present sources of phosphorus are the bones of buffaloes and other animals, slaughtered in the great hunting-grounds of South America (the Pampas bordering the La Plata), where bones are used as fuel; exhausted 'bone-black,' or 'animal charcoal' of sugar refineries; calcareous deposits of phosphate of lime, or 'mineral guano' from the coast of Yucatan; and similar deposits from the island of Sombreros; but the chief of these sources is the burnt bones from Monte Video, Rio Janeiro, Rio Grande, &c., and the animal charcoal of the sugar refineries. These various substances contain from 60 to 90 per cent. of their weight of phosphate of lime, or from 12 to 18 per cent. of phosphorus.

"The phosphorus-yielding material, of whatever kind, having been suitably ground, a weighed quantity of the powder is placed in a large circular tub, lined with lead, with a mixture of oil of vitriol and water, and stirred by means of a revolving wooden stirrer, driven by a steam-engine, steam being admitted by a pipe into the mixture to facilitate the action of the sulphuric acid upon the powder.

"The changes which bone-ash or other varieties of phosphate of lime undergo in the above operation are these: the oil of vitriol or sulphuric acid gradually unites with the lime and forms sulphate of lime, and sets the phosphoric acid free; so that after the process there remains a semi-fluid mixture of a solid substance, sulphate of lime (gypsum or plaster of Paris), with a fluid body, phosphoric acid, separable by filtration.

"The creamy mixture is now transferred, by means of ladles, to a filter or drainer, from which, with the aid of occasional stirring, the phosphoric acid filters into a vessel beneath. Water is added to the drained contents of the filter until the drainings cease to taste acid. The sulphate of lime or gypsum is then removed in its damp state, to a furnace or other source of heat, and dried, and constitutes a residuary product suitable for the manufacture of artificial manures.

"The dilute filtered solution of phosphoric acid, containing some phosphate of lime and a small quantity of sulphate of lime dissolved in it, is transferred to leaden vessels and slowly evaporated over a gentle fire; the small quantity of gypsum then deposits itself upon the bottoms of these vessels, and is removed by scraping. The liquid is deprived of as much more of its water as possible by further evaporation in similar vessels, and on cooling acquires the consistence of cocoa-nut butter.

"The butter-like paste is then well mixed with a due proportion of powdered charcoal, and the mixture heated in furnaces of brick or iron until it is brought

into as dry a powder as can be attained. The powder consists of charcoal, phosphoric acid (a compound of phosphorus and oxygen), a little phosphate of lime, and a little water, which is chemically combined with the phosphoric acid, and not capable of removal by the means yet applied.

"We have already alluded to the intense heat employed by Boyle and Hanckwitz in their distillation of phosphorus: the same is also necessary in the present mode of manufacture. The vessels in which the phosphorus is separated consist of a number (about ten) of small retorts, of a convenient shape, carefully constructed of the most refractory fire-clay, narrowed at their mouths, and arranged nearly close together in a horizontal row in a furnace, somewhat similar to the retorts in a gas-works. They are placed in a nearly horizontal position, with their open ends slightly raised, and in a furnace so constructed as to subject them to nearly a white heat.

"The black powder is introduced into the retorts when the latter are comparatively cool, and the retorts are about half filled with the mixture. Bent pipes, open at both ends, are inserted, air-tight by means of clay, into the mouths of the retorts, and their outer ends dip into warm water, in cast-iron basins, placed to receive the distilled phosphorus. I may now incidentally remark that all the manipulations with ordinary phosphorus in its simple and separated state are performed under the surface of water, otherwise it would quickly inflame and be reconverted into phosphoric acid.

"The heat of the furnace is gradually raised, and in the course of some hours phosphorus begins to distil over, and accumulates in a melted state in the basins of water. The fire is still further raised, by gradual means, until a most intense heat is obtained; the phosphorus then distils rapidly. The heat, after being thus continued as long as any more phosphorus appears, is gradually decreased, and the basins containing the crude phosphorus are removed. The time occupied in the distillation is, in some cases, protracted from forty-eight to seventy-two hours.

"In this operation the charcoal, at a high temperature, combines with the oxygen of the phosphoric acid, forming therewith carbonic oxide and carbonic acid gases, which escape through the nose-pipe, and the phosphorus thus set free is converted into vapour by the heat, and distils over into the receiving-basins. At the same time, the portion of water not extracted by the preceding process is also decomposed, and, its hydrogen set free, combines with some of the phosphorus and forms phosphuretted hydrogen gas. The inflammable gases, carbonic oxide and phosphuretted hydrogen, are conducted away from the phosphorus basins by means of a pipe, and consumed.

"When the distillation is at an end, the furnace is cooled down and the residuary contents of the retorts extracted. The residue consists chiefly of charcoal (of which there is always an excess) and of undecomposed phosphate of lime, together with a few impurities, and is used in the composition of manures, the phosphorus in it being of too difficult or too unprofitable extraction. From the penetrating and destructive character of phosphorus, the retorts require frequent renewing, some manufacturers, when the best fire-clay is not employed, not using them for more than one operation.

"The appearance of a phosphorus distillery containing between 200 and 300 retorts, which we have frequently visited when in full operation and the furnaces at their maximum heat, is somewhat fearful: the long, yellow flames of phosphuretted hydrogen and carbonic oxide shooting forth from the escape-pipes; bits of burning phosphorus spitting forth in fiery balls from little crevices or

leaks at the mouths of the retorts; the incessant bubbling of the vapour of phosphorus and escaping gases in the basins of hot water; the almost unbearable heat from the furnaces on each side, and from the red-hot flues under foot; the intolerable stench of phosphuretted hydrogen and burning phosphorus; together with the acid fumes and filthy grim aspect of the place, combined to produce an impression on our senses which we cannot fail to remember.

"The small cakes of crude phosphorus, each weighing several pounds, are collected from the iron receiving-basins when cold, and melted together under water. The impurities which were carried over from the retorts into the basins by the current of gases and phosphorus vapour, now settle to the bottom of the fluid mass, and the supernatant phosphorus is drawn over into shallow copper pans, containing a small quantity of hot water to prevent contact of air, by means of leaden syphons previously filled with hot water, and allowed to solidify.

"The large cakes or cheeses of phosphorus thus obtained still contain impurities, and are of a dirty red colour, chiefly arising from the mechanical admixture of a red variety of phosphorus in small particles. They are broken to pieces under cold water, and the fragments placed in hot water contained in a leaden vessel (heated by steam), together with a bleaching agent. The phosphorus is stirred with the heated mixture until it is bleached, or its brownish colour is removed, which generally occupies two or three hours.

"The liquid phosphorus is again drawn by means of syphons into shallow copper pans, and allowed to solidify. It is then broken under water, and the pieces are placed in hot water in a double-sided (or steam-jacketed) vertical iron cylinder, lined with lead, with a perforated bottom covered with chamois leather and canvas; and while in the fluid state pressure is applied to the phosphorus, and it passes through the leather, &c., into a vessel of hot water beneath, leaving the residuary impurities, red phosphorus, &c., upon the cloth in the form of a dirty reddish substance of an earthy appearance.

"The bleached and purified phosphorus is now cast into wedge-shaped pieces, or it is moulded into cylindrical sticks, half an inch in diameter, and 10 in. long, by the aid of glass tubes immersed into the phosphorus under water, or by means of an apparatus with tubes specially contrived for the purpose. On some occasions the phosphorus is very brittle and difficult to draw into sticks, but if it is in a satisfactorily pure state it is as ductile as lead or soft copper wire. The appearance of the purified phosphorus in the form of wedges is that of very transparent wax or glass of a slightly greenish-yellow colour, but when in the form of sticks it usually appears colourless. It is needful on all occasions to protect the purified substance from strong daylight, otherwise it soon becomes yellow and opaque. For conveyance it is always packed in water, generally in tin cans, the covers of which are soldered air-tight.

"The phosphorus we have described is that of the ordinary kind; but there is another variety, equally pure, discovered in 1848 by Professor Schrötter, of Vienna, which is produced as follows: The ordinary phosphorus in its purified state is placed under water in a cast-iron boiler over a furnace; then melted, cooled, and the water removed from its surface. The vessel is then immediately and securely closed, air-tight (except a small iron tube for the escape of vapour), by a cast-iron cover. The lid has a vertical iron tube, closed at its lower end, fixed in it, which projects downwards into the phosphorus, and is open at its

upper end for the reception of a thermometer. Heat is now gradually applied by means of the furnace until the phosphorus is at about 450° F., and that temperature is maintained for a greater or less period of time, according to the amount of phosphorus operated upon, and the mass is then allowed to cool. A quantity of about 200 pounds is kept heated about three or four weeks. After this process the vessel is opened, and the phosphorus, which has now become a hard, red brick-like substance, is covered with water, and extracted by means of iron bars, &c. This process of conversion requires to be conducted with great circumspection, otherwise (from overheating of the phosphorus) fearful explosions may ensue; experience has, however, shown that they may be almost wholly avoided.

"For commercial purposes the red or amorphous phosphorus, as it is termed, is required to be in a state of fine powder; the stony fragments are, therefore, broken into small pieces under water in a mortar, and ground under water between pieces of mill-stone in a vessel supplied with a small stream of water, which carries off the finer particles in its overflow stream into a large tank, where they gradually subside, or into a filter where they are collected. A process is then resorted to for the separation of any ordinary phosphorus which the powder may contain.

"This wet and finely-divided substance having been dried, sifted, and packed in air-tight tins, is ready for sale.

"It is well known in modern chemistry that a substance may exist in two or more physical states, possessing very different physical and chemical properties, and that there may be as great a difference in the properties of the same substance in its different states of aggregation as there is between two chemically different substances. For instance, there is as great an amount of physical difference between carbon as it exists in the diamond and as it exists in pure lamp-black as between copper and silver or silver and gold. The two kinds of phosphorus we have described are, then, precisely the same chemical substance, but in different states of aggregation. The following is a comparison of their properties. We will, for convenience, term them white and red phosphorus:

WHITE.	RED.
Poisonous.	Innocuous.
Evolves a strong odour.	Nearly odourless.
Phosphorescent—luminous in the dark.	Not phosphorescent—perfectly illuminous.
Melts at 108° F.	Melts at above 500° F.
Very transparent.	Opaque.
Almost colourless.	Varies in colour from nearly black (with metallic lustre) to iron-grey, brick-red, crimson, and scarlet.
Freely soluble in various liquids.	Nearly insoluble in all liquids.
Distinctly crystalline.	Destitute of all crystalline structure (amorphous).
Soft, may be indented by the nail.	Hard as a common red brick.
Flexible as copper or lead.	Brittle as glass.

"The great and most conspicuous fact is that red phosphorus may be kept in the dry state, exposed to the air, without inflaming; whilst the ordinary variety, under the same circumstances, quickly ignites. The minutest quantity

of ordinary phosphorus in the red or amorphous variety can be detected by digesting the latter, in the state of powder, in bisulphide of carbon, and then letting fall a single drop of the clear liquid upon a saucer floating upon boiling water in a dark place; luminosity will immediately appear if white phosphorus is present.

"There are several uses to which phosphorus has been applied; but, as far as quantity is concerned, almost the only important application is in the manufacture of lucifer matches. It is remarkable that, although the property of phosphorus of igniting by friction was known soon after its discovery, it was not until about the year 1833 that it was successfully applied to the manufacture of matches. It was then sold wholesale at four guineas a pound; in 1837, at two guineas; and at the present time, at less than 2*s.* 6*d.* Manufactories of it exist in Great Britain, France (Lyons), Bavaria, Baden, Austria, and Sardinia.

"Since the commencement of the manufacture of phosphorus upon a large scale in England, in 1845, the value of phosphorus imported into this country has regularly and rapidly decreased. According to the reports of the Great Exhibition of 1851, the value of phosphorus imported from all parts into Great Britain in 1844 was £2,567, and in 1850 only £3. And since that period it has become an article of constant export to the Continent and other parts, the proportion consumed in the United Kingdom being comparatively small. In his 'Catechism of Agricultural Chemistry,' Professor Johnston states that 200,000 lbs. of phosphorus are consumed in London alone per annum. Persons conversant with the actual consumption know that at that time, and probably at the present hour, it would not exceed 20,000 lbs.

"It is also stated in a recent publication on Chemistry, by Professor Muspratt (article 'Phosphorus,' p. 680), that phosphorus 'is prepared as an article of manufacture in large quantities in London and Paris. Kane has calculated that in the latter city alone about 200,000 lbs. are yearly produced.' There may have been once a very small production in London and Paris, but it has long since entirely ceased. The enormous consumption of fuel necessitates that, for an economic production, the manufactory be placed where coal is cheaply obtained; and the quantity of phosphorus produced in all France, at the date of Dr. Kane's book, is not likely to have been at all more than 20,000 lbs. It is plain that, by mistake, a cypher too many has been added."

RED PHOSPHORUS.

Dr. Muspratt describes the following process for preparing this form of phosphorus, which is effected in the apparatus shown in Fig. 501. A quantity of common dried phosphorus is placed in the flask A, to the neck of which a long narrow tube, *b*, bent downwards, is attached, the open end of which dips into a little mercury. The removal of the air is accomplished by means of a current of carbonic acid evolved from the bottle E, containing marble and hydrochloric acid. The gas is dried by passing it over chloride of calcium contained in the tube F. The flask being emptied of air, the tube is closed by fusion at the narrow portion, *a*, and the apparatus evolving carbonic acid removed. The flask is then heated by means of an oil bath, *c*; the phosphorus melts readily, and by regulating the heat steadily between 450° and 460° by means of a thermometer, *t*, and maintaining it thirty or forty hours, nearly the whole will be converted into the solid amorphous variety. When the meta-

morphosis appears to be complete, the apparatus is allowed to cool. Any unaltered phosphorus is separated by digestion in bisulphide of carbon, in which amorphous phosphorus is insoluble. The latter is afterwards collected in a filter and washed with bisulphide of carbon, as long as anything is removed from it, which may be ascertained by evaporating a small portion in a watch-glass, when any dissolved phosphorus will remain behind.

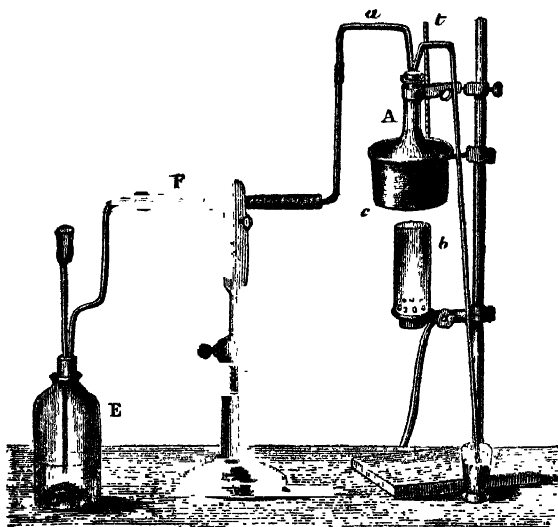


FIG. 501.

Crystals of phosphorus having a bright metallic lustre and a specific gravity of 2·34—nearly double that of ordinary phosphorus, which has a specific gravity of 1·83—may be obtained by dissolving amorphous or red phosphorus in melted lead. Amorphous phosphorus has a specific gravity of 2·14.

There are two oxides of phosphorus which are anhydrous, viz.—

Phosphoric trioxide (phosphorus anhydride), P_2O_3;
Phosphoric pentoxide (phosphoric anhydride), P_2O_5;

The latter represents the dense white smoke that passes off when phosphorus is burnt in a cup, so that the air does not have free access to it; or if phosphorus is burnt under a bell-jar in dry air, a quantity of a snow-white flocculent non-crystalline substance collects on the sides of the glass, or falls chiefly to the lower part if the glass is standing on a marble disc. This substance is phosphoric pentoxide, and, like sulphuric trioxide, hisses like a red-hot iron when brought in contact with water. The equation is $P_2O_5+3H_2O$, the phosphoric pentoxide having united with three molecules of water to form $2H_3PO_4$, two molecules of tribasic phosphoric acid. There are two other acids of phosphorus,—dibasic and monobasic; the hydrogen being the base, as already explained, that determines the rank of the acid.

1. Monobasic hypophosphorous acid . . HPH_2O_2;
2. Dibasic phosphorous acid . . . H_2PHO_3;
3. Tribasic phosphoric acid . . . . H_3PO_4.

As there are three allotropic conditions of phosphorus, so there are three varieties of phosphoric acid—in fact, different acids:

Tribasic phosphoric acid, H_3PO_4;
Pyrophosphoric acid, $H_4P_2O_7$;
Metaphosphoric acid, HPO_3.

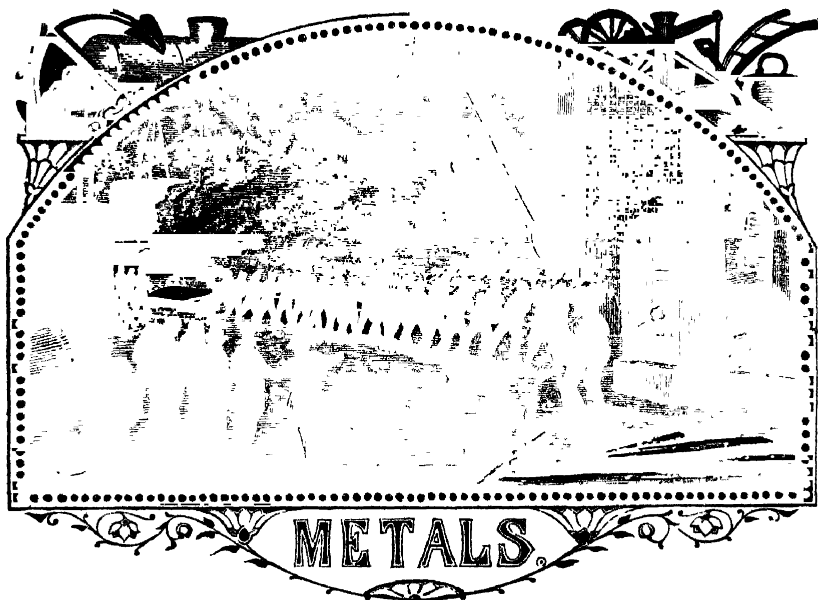
Each of these acids forms its own peculiar metallic salts.

Tri-sodium phosphate (Na_3PO_4) dissolved in water precipitates from argentic nitrate a *yellow* precipitate of triargentic phosphate (Ag_3PO_4). Sodium pyrophosphate ($Na_4P_2O_7$) with the same silver salt forms a *white* precipitate, consisting of $Ag_4P_2O_7$. Sodium metaphosphate ($NaPO_3$) forms with the same silver salt—argentic nitrate—a gelatinous white precipitate ($AgPO_3$) quite different from the other two.

There are three compounds of phosphorus and hydrogen. One is a solid, and called solid phosphide of hydrogen (HP_2); the second is a liquid, termed liquid phosphide of hydrogen (H_2P); and the third a gas, phosphuretted hydrogen (H_3P). The last-named compound has the peculiar property of taking fire spontaneously when brought in contact with the air, and is generally prepared by placing some phosphorus in a retort, and then filling the latter, neck and body, with a solution of caustic potash. By boiling the solution of potash this gas is eliminated, and, when it has filled the upper part of the retort and driven the fluid out of the neck, every bubble that escapes takes fire spontaneously, forming a beautiful ring of white smoke. Of course the neck of the retort must be kept under water, and if it is allowed to dip into a small basin containing more solution of potash, the retort and its contents may be used for several days to show the evolution of phosphuretted hydrogen; because, when the retort is allowed to cool, solution of potash fills the void that is created, and if air entered instead of the solution, an explosion would most likely occur that might burst the retort.

There are chlorides, bromides, and iodides of phosphorus, and a phosphide of nitrogen called phosphane by Gerhardt, who has laboured so industriously to reform chemical nomenclature.

Sulphur and phosphorus unite, forming compounds, in two of which the molecules unite in the same relative proportions as phosphorus anhydride (P_2O_3) and phosphoric anhydride (P_2O_5), the corresponding sulphur compounds being P_2S_3 and P_2S_5.



THE METALS.

TELLURIUM.

Symbol, Te. Atomic weight, 129. Specific gravity, 6·25.

Henry Watts, in his "Dictionary of Chemistry," agrees with other scientific writers in stating that "this element, though decidedly metallic, must be classed as a member of the sulphur family, as it approximates very closely in its chemical character to sulphur, and still more to selenium. It was first identified as a distinct metal by Klaproth in 1798, who gave it the name 'tellurium,' from Tellus, the mythological name of the earth. Tellurium is one of the rarer metals, being found in a few localities only, and chiefly in Hungary and Transylvania."

"Tellurium in its chemical relations bears a very close analogy to sulphur and selenium. It forms two oxides—tellurous oxide (TeO_2) and telluric oxide (TeO_3)—which, in combination with water and with metallic bases, yield acids and salts analogous to those formed by the corresponding oxides of sulphur and selenium."

Tellurium crystallizes, and has a bright tin-like metallic lustre; it melts at about 800 or 900° F., and at a high temperature is converted into a yellow vapour. It burns when strongly ignited in air, with a blue flame edged with green, emitting a peculiar odorous vapour. Swallowed in minute quantities, it imparts to the breath a strong garlic flavour.

Telluretted hydrogen (H_2Te) is a gaseous body very like sulphuretted hydrogen; in fact, its odour is almost identical with that of the latter.

Tellurium is a bad conductor of electricity and heat, and is thus early spoken of because of its analogy to the non-metallic bodies sulphur and selenium.

ARSENIC.

Symbol, As. Atomic weight, 75. Specific gravity, 5·70 to 5·95.

The consideration of this metal is entered upon here because, like tellurium, it has certain chemical characteristics which place it closely in analogy with non-metallic elements, viz., phosphorus and nitrogen; at the same time it has other physical qualities that bring it in close proximity to the two metals antimony and bismuth.

Arsenic may be regarded as an intermediate link between the non-metallic bodies already considered and the metallic elements which have next to engage our attention. In the brief summary of each metal, its sources, and its physical and chemical properties, will be considered.

Sources of Arsenic.

The greater part of the arsenical pyrites (mispickel, FeAsS), from which the white oxide of arsenic is procured, is found in Bohemia, Norway, Sweden, Hungary, Saxony, and other places on the Continent. Arsenic occurs as an alloy with tin, copper, cobalt, and nickel; also united with oxygen and certain metals, as in the arseniates of copper, lead, and iron.

There are natural sulphides of arsenic, viz., the red sulphide, called realgar, and the yellow, termed orpiment.

Arsenic is occasionally found in the native state, and is one of the most widely diffused natural bodies, being sometimes contained even in mineral springs.

White arsenic, arsenious oxide, or trioxide of arsenic (As_2O_3) is obtained by roasting the sulphide of iron, or other minerals containing arsenic, in a reverberatory furnace connected with a long chimney, which is nearly horizontal, but terminating in a tower of brickwork also divided into compartments, so that all the volatile products shall be condensed during the slow passage of the current from the reverberatory furnace.

The crude arsenious oxide is purified by sublimation, and, being heated in a retort with charcoal, is reduced to metallic arsenic, which sublimes into the receiver.

Physical Qualities of Arsenic.

The metallic nature of arsenic was discovered by Brandt in 1733. It is of a steel-grey colour, easily tarnishing in air, but retaining its brilliant aspect under water, especially if the latter is first boiled and placed with the arsenic in an air-tight bottle. It is very brittle, and easily pounded in a mortar.

Arsenic has no smell when cold, and, if heated, does not melt, but sublimes easily, and then emits a strong odour resembling garlic. Tubes for experiments with arsenic may be obtained from Mr. How, of Foster Lane, Cheapside. A certain quantity of the metallic arsenic is usually oxidized in the presence of air. It is a most violent poison, and hence derives its

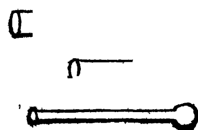


FIG. 502.—*Tubes for experimenting with Arsenic.*

name from αρσενικον (powerful), on account of the small quantity sufficient to cause death.

CHEMICAL PROPERTIES OF ARSENIC.

Arsenic combines with the metals like sulphur or phosphorus, and, when heated in the air, ignites, burning with a bluish flame and forming arsenious oxide. It takes fire immediately when powdered and dropped into chlorine gas, forming arsenic trichloride ($AsCl_3$). There are two oxides of arsenic: the sesquioxide or arsenious anhydride, arsenious acid, arsenic trioxide (As_2O_3), and arsenic anhydride, arsenic pentoxide, or arsenic oxide (As_2O_5). The preparation of the first-named compound has already been described; the second, arsenic pentoxide, is obtained by digesting white arsenic with nitric acid, and then boiling down the solution in a platinum or hard porcelain vessel.

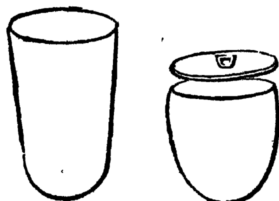


FIG. 503.
Hard Porcelain Cups and Crucibles for analytical purposes.

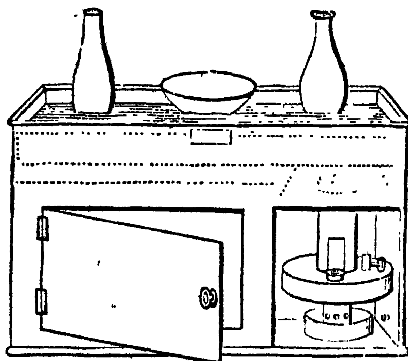


FIG. 504.—*Portable Sand Bath and Oven, heated by an Oil Lamp.*

In the absence of a supply of coal-gas, and especially where operators amuse themselves in the country with chemical experiments, a steady moderate heat is often required for the solution of various minerals and metals in acids or other solvents; this is conveniently obtained with a sand bath heated by a common Argand oil lamp, which is so arranged that the heat shall be economized, and whilst imparting it to the sand above, a small oven is also warmed, in which precipitates or filters may be easily dried.

Arsenic is employed for various purposes: it is used in the manufacture of small leaden shot; it enters into the composition of the alloys of tin and copper used in making metallic speculæ for telescopes. In fluxing certain kinds of glass, and oxidizing the ferrous oxide to get rid of the green tinge, it is found to be very useful.

There are many pigments which owe their brilliancy to the presence of this metal, as "Scheele's green," or hydrocupric arsenic ($CaHAsO_3$), or Schweinfurt green, a cupric arsenite and acetate ($3CaAs_2O_4$, $Ca_2C_2H_3O_2$).

Arsenic is employed to prevent smut in grain and in poisoning vermin, and being such a terrible poison easily obtainable, it is not surprising that poor

ignorant criminals should use it for destroying human life, always forgetting that, although so readily procured, it is still more easily detected.

The characteristic results obtained by using the proper reagents or tests for arsenic are unmistakable.

The testing operations for arsenic may be conducted on the smallest possible scale, and yet are most conclusive, and for this purpose plenty of clean dry test tubes should be provided.

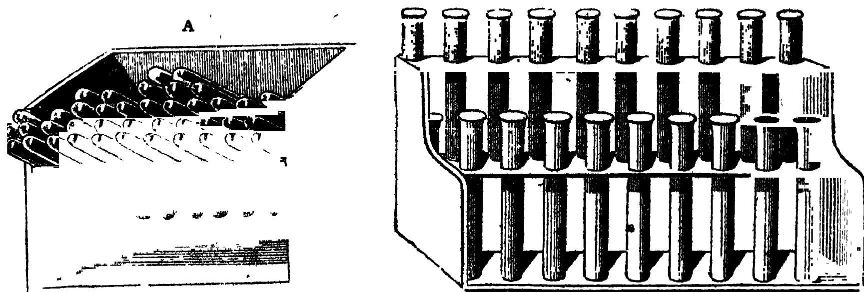


FIG. 505.
A, test tubes washed and draining, to be placed in rack B for use.

The identification of arsenic may be conducted with quantities so minute as to be inappreciable by the balance. The presence of arsenic in any mineral is readily detected by the skilful use of the blowpipe. A fragment of mispickel (FeAsS) is powdered, and heated with dry carbonate of soda and charcoal before the blowpipe, a well-trained nose soon detects the peculiar garlicky odour when the heat is applied.

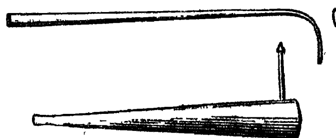


FIG. 506.—*Various Blowpipes used by Chemists and Mineralogists.*

The flame of a spirit lamp will answer for most of the blowpipe experiments, and when gas is laid on there is usually a jet attached to the mixed air and gas burner for this purpose. As an illustration of the convenience of the gas burners, Normandy's burner with blowpipe gas jet is shown in Fig. 507.

When in solution, the compounds of arsenic are detected by the following tests:

If the arsenic be in the condition of arsenious acid, and supposing the organic matters removed by processes all described in works on toxicology,

solution of nitrate of silver with a drop of ammonia causes a yellow precipitate of triargentic arseniate, freely soluble in excess of ammonia or in nitric acid. Sulphuretted hydrogen causes a yellow precipitate of arsenious sesquisulphide: this must be allowed to subside, and is then collected, dissolved in ammonia, and evaporated to dryness on a water bath. The dry sesquisulphide is reduced to the metallic state by mixing it with some potassic cyanide and sodic carbonate, all well dried and mixed; and placing it into one of the tubes, Fig. 502, the mixture is now heated strongly by the blowpipe, and the metallic arsenic condenses in the upper part of the tube, giving to it the appearance of a brilliant mirror having a steel-grey aspect. Solution of sulphate of copper with a drop or so of ammonia throws down a green precipitate, hydrocupric arsenite or Scheele's green. A little solution of arsenious acid evaporated to dryness with nitric acid, and converted into arsenic acid, and then redissolved with the addition of a drop of ammonia, gives the marked brick-red precipitate, when a solution of nitrate of silver is added. The brick-red precipitate is triargentic arseniate (Ag_3AsO_4).

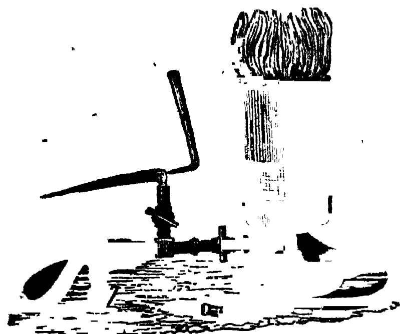


FIG. 507.—*Dr. Normandy's Burner, with independent Blowpipe Flame.*

Marsh's test is one of the most conclusive when the inquiry is made for judicial purposes. A bottle, A, fitted with a cork and small funnel, is charged with pure granulated zinc and water; to this is adapted a tube, B, containing calcic chloride, to stop any particles of fluid that might be carried over mechanically; to the last-named tube is attached a bulb, C, drawn out to a capillary

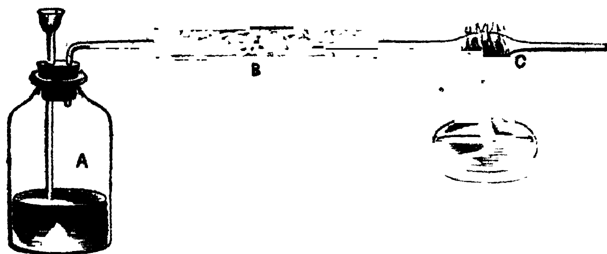


FIG. 508.—*Marsh's Test for Arsenic.*

tube, and made of hard German glass, and under which (when all the atmospheric air is driven out by the current of hydrogen formed by pouring pure sulphuric acid down the funnel attached to A) the flame of a spirit lamp is placed, at the point just where the capillary portion of the bulb tube commences. Ten minutes are allowed to ascertain if all the materials are pure, and that no deposit whatever takes place in the bulb. The solution supposed to contain the

arsenious acid is now poured down the funnel into A, and, if arsenic be present, arseniuretted hydrogen (H_3As) is formed, and decomposed as it passes through the heated tube, the metal being deposited like a ring of burnished steel just beyond the part where the heat is applied. Marsh's test, taken in conjunction with Reinsch's test and the others already described, affords evidence which is indisputable. The arseniuretted hydrogen, if allowed to escape through the cold bulb and inflamed at the aperture, burns with the peculiar flame of arsenic; and if a cold piece of porcelain be held against the flame, rings of metallic arsenic are deposited, distinguishable from antimony, which behaves in a similar manner, by the fact that antimonial stains disappear when a drop of ammonia sulphide in which a little sulphur is dissolved is added, whilst the arsenical crusts are hardly affected by the same re-agent.

ANTIMONY.

Symbol, Sb (Stibium). Atomic weight, 122.

It has already been mentioned that arsenic, antimony, and bismuth closely resemble phosphorus in their chemical, though not exactly in their physical, qualities; this group of three metals is therefore taken first, because it is the connecting-link between the non-metallic and metallic elements.

Sources whence Derived.

Antimony, though sometimes found native, is chiefly derived from the ore or sesquisulphide (Sb_2S_3), which is found in Hungary, Norway, Saxony, and Sweden. This ore is first purified from the earthy matter: by exposure to a strong heat in a reverberatory furnace the ore melts and separates from the impurities, and is cast into cakes called crude antimony.

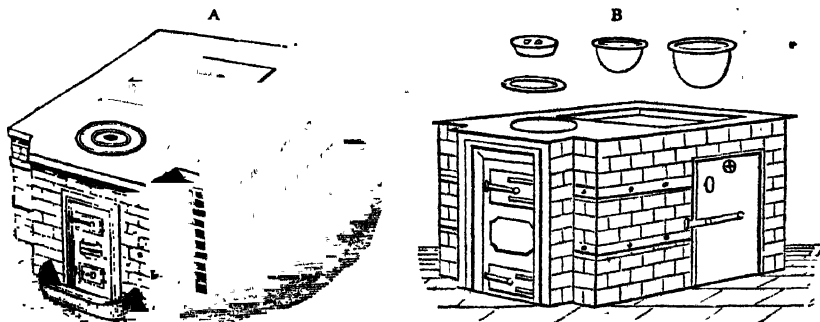


Fig. 509.—*Useful forms of Furnaces, with Sand Bath and Oven,*
And various-sized rings and iron pots for chemical purposes.

If 4 parts of crude antimony, 3 of crude tartar, and $1\frac{1}{2}$ of nitre are thoroughly powdered and mixed, and thrown gradually into a Hessian crucible kept at a bright red heat, the ore is reduced to the metallic state. A furnace with a capacious and tall chimney can be built so that the whole draught is con-

nected with the fireplace, or diverted when required, by proper dampers, to a sand bath, as at A, Fig. 509, or it may heat an oven and sand bath, as at B, Fig. 509.

PHYSICAL PROPERTIES OF ANTIMONY.

This metal was discovered by Basil Valentine at the latter end of the fifteenth century, and is so called from the Greek αντι, against, and μονος, a monk, because it is stated that some monks were unfortunately poisoned by medicine prepared from this metal. Antimony is crystalline and has a brilliant silvery-white aspect, and, having very little tenacity or ductility, is therefore easily powdered. The specific gravity of this metal is 6·715, and it melts at about 1,150° F. It is used in forming various important alloys, such as type and britannia metals and pewter. The well-known medicine called James's Powder contains this metal and "tartar emetic;" a true chemical compound of potassium, oxide of antimony, tartaric acid, and water is also extensively used in the healing art.

CHEMICAL PROPERTIES OF ANTIMONY.

Antimony retains its brilliancy when exposed to the air; but if melted rapidly it changes by combining with the oxygen of the air. If the heat is strongly urged it will burn with a white flame, forming a heavy white smoke—the antimonic trioxide. Powdered antimony takes fire when thrown into chlorine gas, and becomes very hot if brought in contact with iodine and bromine, with which it also unites. Aqua regia, nitro-hydrochloric acid, dissolves antimony freely; if nitric acid be used alone, the metal is converted into a straw-coloured insoluble antimonic oxide: boiling hydrochloric acid will dissolve it. Metallic antimony is also dissolved when digested in fine powder with a solution of one of the sulphides of potassium.

Antimony forms three oxides:

Antimonious oxide, Sb_2O_3;
Antimonic oxide or anhydride, Sb_2O_5;
Antimonious antimoniate, $Sb_2O_3.Sb_2O_5$.

It is the first of these oxides which is used in medicine.

This metal-like arsenic unites with hydrogen, forming antimoniuretted hydrogen, having the probable constitution of SbH_3, and is evolved whenever the metal is brought in contact with zinc and dilute sulphuric acid.

There are many niceties required in the discrimination of this metal from arsenic; and as both metals are used by poisoners, the reader is referred to the best works on toxicology for the analytical processes required, not only to detect antimony, but also to distinguish it from arsenic.

BISMUTH.

Symbol, Bi. Atomic weight, 210.

SOURCES WHENCE DERIVED.

Bismuth, though not a rare metal, is by no means abundantly distributed throughout the crust of the earth. It occurs native in Saxony, Bohemia, and Transylvania, and is simply melted out of the crushed quartz with which it is

associated. It also occurs with cobalt in the cobaltic ores of Saxony and England. A sulphide of bismuth, called "bismuth glance" (Bi_2S_3), is another natural mineral containing this metal.

Physical Properties.

In some works bismuth is described as a yellowish-white metal, but it is in fact reddish-white: this apparent difference in the bloom or tint of the metal was observed by the discoverer Agricola in 1529, who called it "*Wiessmatte*," "a blooming meadow," on account of the variegated hues of its tarnish. It has a specific gravity of 9·799, reduced by Marchand and Scheerer (who, apparently, compressed the internal cavities in the specimen of bismuth they used) to 9·556. The metal is easily fusible, and melts at a temperature of 507° F. Bismuth, like antimony and arsenic, has little malleability, ductility, or tenacity, and is so brittle that it may be easily reduced to powder under the hammer.

On account of the singular property it possesses of *expanding* when cooling it is extremely valuable in testing the progress of a die, and is therefore constantly employed by die-sinkers, who, with type-makers, call it "tin glass."

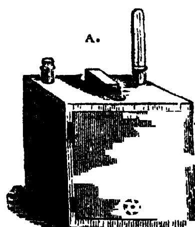
Chemical Properties.

Bismuth is slightly volatile when strongly heated, and, like arsenic, tarnishes in the air, but not so if kept in a well-stoppered bottle containing boiled distilled water. At a red heat bismuth quickly oxidizes, and also takes fire in chlorine when very finely powdered and dropped into that gas. Sulphur, bromine, and iodine all unite with this metal.

Bismuth is quickly dissolved by nitric acid, which is its proper solvent.

Two oxides of bismuth are known: bismuth oxide or sesquioxide of bismuth (Bi_2O_3), and an acid oxide or anhydride (Bi_2O_5).

The nitrate ($Bi_3NO_3 5H_2O$) appears to be the best known and most important salt of bismuth. When the solution is largely diluted with water, an insoluble basic compound is formed, or sub-nitrate ($Bi_2O_3 2HNO_3$). This precipitate, when collected and moderately washed and dried, is the well-known cosmetic, so freely prescribed by the improvers of complexions, called "pearl white." The old alchemical writers called it the "magistery of bismuth." For drying precipitates various convenient ovens are made by Mr. How, of Foster Lane. When surrounded by water and the steam allowed to escape freely, the oven, of course, does not afford a heat higher than 212° F.



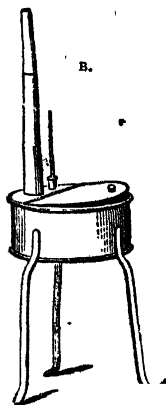


Fig. 510.

A, oven heated by boiling water; B, hot air oven, heated by gas, oil, or a spirit lamp.

The hot air oven is heated from below with a gas-flame; a much higher temperature may be obtained, and conveniently regulated by a thermometer. No solder is used in the construction of these ovens, which are most useful for drying precipitates.

The general chemical analogy between nitrogen, phosphorus, arsenic, antimony, and bismuth is well shown by tabulating some of the compounds having the same number of combining molecules.

N_2O_3	Nitrous anhydride.
P_2O_3 . . .	Phosphorus do.
As_2O_3	Arsenious do.
Sb_2O_3	Antimonious do.
Bi_2O_3	Bismuthous do.

CLASSIFICATION OF THE METALS.

Although the metal tellurium, and the group of metals, arsenic, antimony, and bismuth, have been discussed because of their remarkable anology to certain bodies belonging to the non-metallic substances, the arrangement of the whole of the metals in proper groups must not be omitted, because the student is so much assisted by studying them not only individually, but in their relations to each other.

Gmelin arranges the metals in six groups, Dr. Miller in eight, and Professor Roscoe in eleven classes, the latter of which will be adopted.

I. Metals of the Alkalies (*five in number*).

1. Potassium 3. Lithium 5. Rubidium
2. Sodium 4. Cæsium (?) Ammonium

II. Metals of the Alkaline Earths (*three in number*).

1. Barium 2. Strontium 3. Calcium

III. Metals of the Earths (*nine in number*).

1. Aluminium 4. Erbium 7. Lanthanum
2. Glucinium 5. Zirconium 8. Didymium
3. Yttrium 6. Cerium 9. Thorium

IV. Zinc Class (*three in number*).

1. Magnesium 2. Zinc 3. Cadmium

V. Iron Class (*seven in number*).

1. Cobalt 3. Uranium 6. Manganese
2. Nickel 4. Iron 7. Indium
5. Chromium

VI. Tin Class (*four in number*).

1. Tin 2. Titanium 3. Niobium 4. Tantalum

VII. Tungsten Class (*three in number*).

1. Molybdenum 2. Vanadium 3. Tungsten

VIII. Arsenic Class (*three in number*).

1. Arsenic 2. Antimony 3. Bismuth

IX. Lead Class (*two in number*).

1. Lead 2. Thallium

X. Silver Class (*three in number*).

1. Copper 2. Mercury 3. Silver

XI. Gold Class (*seven in number*).

1. Gold
2. Platinum
3. Palladium
4. Rhodium
5. Ruthenium
6. Iridium
7. Osmium

CLASS I.

POTASSIUM, SODIUM, RUBIDIUM, CÆSIUM, LITHIUM, AMMONIUM.

Metals of the Alkalies.

POTASSIUM.

Symbol, K (Kalium). Atomic weight, 39·1.

Potassium monoxide (K_2O), united with water, forms potassium hydrate (HKO), commonly called *potash*, and gives the name to this metal, so called from the pots in which the ashes of land plants, wood, &c., were lixiviated, boiled, and evaporated to the dry substance called pot-ashes. It was discovered by Davy in 1807.

Sources whence Derived.

Our daily food, made up of animal and vegetable substances, most of which contain salts of potassium, conveys to the human body this metal, which appears, in combination with other elements, to be an essential constituent of flesh, milk, &c.

This element is very plentifully distributed throughout the mineral world. It is found as a nitrate in the soils of certain hot climates; in sea-water, in certain springs, also in salt deposits are to be found iodides, bromides, and chlorides of potassium. Feldspar and mica are examples of common mineral bodies that contain potassium in the form of silicates.

When plants and trees are burnt, the organic acids with which the potash was united are changed to carbonates, and thus the wood-ashes contain potassic carbonate (K_2CO_3). The commercial process now approved for obtaining potassium is that of decomposing potassic carbonate by charcoal. Crude tartar—formerly called bitartrate of potash, but now termed hydro-potassic tartrate, being, in fact, the crust deposited from wine—is first heated in a covered crucible until all vapours cease escaping; the residue, a porous mass consisting of potassic carbonate and finely-divided charcoal, is broken up into lumps, and transferred to a wrought-iron bottle (such as that delineated on page 545), provided with an iron tube; the bottle is supported in a proper furnace, and, when red hot, is dusted over with powdered fused borax: this simple coating protects the bottle from oxidation, and enables the heat to be gradually raised to a full white heat. When the vapour of potassium begins to appear and burns with a brilliant light, a peculiar shaped receiver is attached,

and kept cool with a damp cloth. The receiver is attached as close as possible to the generating-bottle, and, should the potassium choke up the neck, a provision is made to remove the obstruction with a sliding rod. Finally, the receiver is plunged into Persian naphtha, and when cold the potassium is removed and preserved under naphtha. The crude potassium is always re-distilled, to get rid of a peculiar black detonating compound, and, when required very pure, is even distilled again.

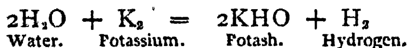
Physical Properties of Potassium.

This metal has a specific gravity of 0·865, and is the lightest of all metals except lithium: its specific gravity shows that it will float on water. At 0° F. it is crystalline and brittle, and at ordinary temperatures is very malleable—or rather, in this case, soft and pasty—and becomes perfectly liquid at 144° 5′ F. Two clean surfaces are easily welded or squeezed together; indeed, the ordinary terms as applied to other metals—such as malleability, ductility, and tenacity—may be exchanged for the general one of plasticity.

Potassium is a bluish-white metal, and, when freshly cut, retains its brilliancy for a short time only, being speedily covered with oxide. Potassium may be crystallized by melting some in a sealed tube, and just at the point of solidification, when a few solid points appear, if the fluid portion is poured away by inverting the tube, the residue crystallizes in the form of shining octohedral crystals.

Chemical Properties.

Potassium burns with a violet light when heated in the air, or, if thrown on water, is so rapidly oxidized and heated that the escaping hydrogen takes fire, and burns with a rose-red flame, because some of the potassium volatilizes and burns with it. The resulting potassic hydrate (KHO) takes the form of a liquid red-hot ball, and, gradually cooling, appears like glass; and then coming in contact with the water, from which it was repelled whilst hot by the escaping vapour on the spheroidal system, it bursts into a number of small particles, any one of which entering the eye would cause great pain. Each atom of potassium displaces half the hydrogen of an atom of water, and potassium hydrate is formed.



$$2H_2O + K_2 = 2KHO + H_2$$

Water. Potassium. Potash. Hydrogen.

There are three distinct oxides of potassium, viz.—

1. Potassium dioxide . . . . . . K_2O_2
2. Potash or potassium monoxide . . . K_2O
3. Potassium tetroxide or peroxide of potassium K_2O_4

The chief salts of this metal are potassium carbonate (K_2CO_3); potassium nitrate, nitre or saltpetre (KNO_3), used so extensively in the manufacture of gunpowder, which contains

Nitre	75	parts by weight,
Charcoal . . .	15	,, ,,
Sulphur . . .	10	,, ,,
	100;	

Potassium chlorate ($KClO_3$), already mentioned as an important source of oxygen gas; and potassium sulphate (K_2SO_4).

Potassium forms various compounds with sulphur, viz.—K_2S, K_2S_2, K_2S_3, and K_2S_5. It also unites with chlorine, iodine, bromine, and fluorine, and curiously absorbs a large quantity of hydrogen (HK_4) at a dull red heat, but gives off the gas again at a higher temperature.

The tests for salts of potassium are applied after all other metals except sodium are removed. The solutions tested should be concentrated, and for this purpose hard porcelain dishes, with or without handles, also strainers and ladles for dipping out any crystals for examination with a magnifying-glass, can be obtained from Mr. How.

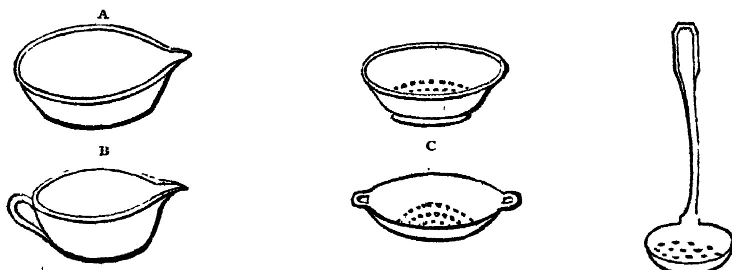


FIG. 511.
A, B, evaporating-dishes; C, D, porcelain strainers.

The concentrated fluid supposed to contain potash is tested with a solution of tartaric acid in excess, and, if briskly stirred, crystals of hydro-potassic tartrate ($KHC_4H_4O_6$) are formed. The best test is platinic chloride, which forms a yellow double salt with potash ($2KCl$, $PtCl_4$), insoluble in alcohol and ether, but slightly soluble in water.

SODIUM.

Symbol, Na (Natrium). Atomic weight, 23.

This metal was also discovered by Davy in 1808, and is so called from the alkali soda, originally obtained from the ashes of the Salsola soda.

SOURCES WHENCE DERIVED.

Sodic chloride, or common salt, is of course the great source from which this metal is obtained. Sodic chloride exists in solid beds in Cheshire, or is obtained by the evaporation of sea-water. Common salt is converted into sodic carbonate, and from this, by the action of charcoal mixed with chalk, and with the assistance of an intense heat, sodium is now obtained at a very cheap rate. The process is very much like that required in the manufacture of potassium, and the metal is now used extensively in the preparation of aluminium, magnesium, &c.

PHYSICAL PROPERTIES.

Sodium is a silver-white metal with a bluish aspect, plastic and soft like potassium at ordinary temperatures, and fusing at 207° 7′ F. When dropped

into cold water it does not appear to produce enough heat to set fire to the hydrogen escaping around it; if, however, the water is thickened with starch, or hot, or if the sodium is placed on a piece of wetted blotting-paper, the heat accumulates, and then the hydrogen burns with the metal, which emits a bright yellow light. The specific gravity of sodium is 0·972.

Chemical Properties.

Sodium volatilizes at a heat below redness; it tarnishes directly it is exposed to the air, and forms two oxides:

Soda or sodic oxide	$Na_2O = 62$.
Sodic peroxide	$Na_2O_2 = 78$.

The chief salts are sodic chloride (NaCl), sodic nitrate or *cubic nitre* ($NaNO_3$), and sodic carbonate (Na_2CO_3); the latter represents in its manufacture one of the great commercial elements of wealth in this country, and involves processes conducted on the largest scale by which common salt is converted into "salt cake," then into "black ash," and finally, by lixiviation and evaporation, the soda-ash—viz., the carbonate—is obtained.

The phosphates of sodium, sodium borate, or borax (Na_2O_2, $B_2O_3 + 10H_2O$), the sodic silicates or soluble glass, and sodic hyposulphite ($Na_2S_2H_2O_4 + 4H_2O$), used in photography, are other examples of useful sodium salts.

Sodium is recognized by the yellow colour it imparts to flame, and all the sodium salts except the antimoniate being soluble in water, the detection of this metal is effected rather by a negative than a direct process. The spectroscope is most usefully applied in this and many other cases where the presence of a minute quantity of any metal is suspected.

RUBIDIUM.

Symbol, Rb. Atomic weight, 85·54.

This metal, so called from the Latin *rubidus*, dark red, was first discovered with the spectroscope by Bunsen and Kirchoff between 1860 and '61. It is said to be a white metal capable of rapid oxidation, and having a specific gravity of 1·52. It is present in small quantities in lepidolite, and was originally discovered in the mineral water of Dürkheim. At 14° F. it is soft, and melts at 101° 3′ F. At a temperature below a dull red heat it is converted into a blue vapour shaded with green. Like potassium, rubidium takes fire when thrown upon water.

Rubidia (Rb_2O) is the only oxide of rubidium known, and rubidic chloride, sulphate, nitrate, carbonate, and hydro-rubidic carbonate or bicarbonate are some of the salts of this rare metal which have already been investigated.

CÆSIUM.

Symbol, Cs. Atomic weight, 133.

This metal was also discovered by spectrum analysis, and so called by its discoverers, Bunsen and Kirchoff, from *cæsius*, sky-blue, in allusion to the two brilliant blue bands produced by it in the flame used for its volatilization.

Some idea of the searching nature of spectrum analysis may be formed from the fact that 140 gallons of the Dürkheim water in which it was first discovered contain only one grain of a salt of cæsium. Pisani has, however, discovered cæsium in a rare mineral called Pollux, found in the island of Elba: the mineral contained 32 per cent. of cæsium.

Cæsia (Cs_2O), cæsic chloride ($CsCl$), cæsic sulphate (Cs_2SO_4), cæsic nitrate ($CsNO_3$), and cæsic carbonate (Cs_2CO_3) are some of the compounds of this metal which have been obtained.

Both rubidium and cæsium closely resemble each other and potassium, and cæsium is separated from rubidium by taking advantage of the greater solubility of the cæsic tartrate.

LITHIUM.

Symbol, Li. Atomic weight, 7.

Lithium (from λιθος, a stone) was formerly supposed to be a very rare metal, but, since the use of the spectroscope, is found to be contained in various mineral springs, the ashes of tobacco, and in certain micas and feldspars. Lepidolite or lithic mica, triphane or spodumene, and petalite are the three minerals that contain it in the largest quantity, and even that is small, and does not exceed from 3 to 6 per cent.

The specific gravity of lithium (the lightest solid known) is only 0·5936. It volatilizes at high temperatures. If thrown on water it behaves very much like sodium, and produces a most intense heat when burnt in the air. It is usually prepared by decomposing the fused chloride by electricity. The metal is of a white colour, and melts at 356° F.

Lithia (L_2O), lithic hydrate (LHO), lithic chloride, sulphate, phosphate, and carbonate have been examined, and all the volatile lithium salts impart a beautiful crimson tinge to flame. The spectrum of lithium is one of the most beautiful that can be projected on to the disc by the electric lamp and voltaic battery.

AMMONIUM.

Theoretical atomic weight = 18.

It has long been supposed that there exists another metal, or *quasi* metal (NH_4), called ammonium; thus ammonium chloride (H_4NCL), the most important of the salts derived from ammonium, when employed in solution to moisten an amalgam of potassium and sodium, causes the latter to increase eight or ten times in bulk. The appearance of the swelled-out amalgam is peculiar: it retains its brilliancy, at the same time appears pasty; and if this body is reduced in temperature to zero or 0° F., it assumes the solid condition, and crystallizes in cubes. In the pasty state it gradually decomposes spontaneously, but more rapidly when placed in water, when *hydrogen* escapes, and ammonia is found in solution. A metal is always defined to be an element; how then can NH_4 belong to that class? Is it not more probable that hydrogen is really the metal that puffs out and combines with the mercury? The idea receives a remarkable corroboration from the following experiment, which the writer was kindly shown by Mr. Roberts:

"*Hydrogenium a Metal.*—At the Royal Society's *conversazione*, Mr. W. C. Roberts (for Mr. Graham, the Master of the Mint) exhibited a curious example of the absorption of hydrogen by palladium, and consequent alloy and expansion of the metal. A coiled ribbon of palladium was attached to each pole of a small battery in a water bath. The current being turned on, the ribbon absorbs hydrogen, expands, uncoils, and stretches itself across the bath; then, on reversal of the current, shrinks, and re-forms its coil, while the opposite ribbon goes through the opposite process. The appearance is that of two worms wriggling alternately to and fro across the bath. In another instance the expansion was shown by a red-tipped arrow making bold sweeps half round a circle. These experiments demonstrate the enormous capacity of palladium for absorption of hydrogen, and verify Mr. Graham's conclusions."

CLASS II.

CALCIUM, STRONTIUM, BARIUM.

Metals of the Alkaline Earths.

CALCIUM.

Symbol, Ca. Atomic weight, 40.

Mountain limestone, marble, chalk, gypsum, marls, and various soils are all common sources from whence this metal may be derived. It is, however, usually procured from calcium iodide by the action of metallic sodium, and is then described as a yellow metal, like pale gold, having a specific gravity of 1·580. Calcium was discovered by Davy in the year 1808, and obtained by him from lime, a substance long called a calx or earth. In hardness calcium takes an intermediate position between gold and lead, and can be beaten into very thin leaves. When exposed to dry or damp air, it tarnishes and is gradually oxidized. When heated, it burns with a white light, forming the only oxide, called calcic oxide or lime (CaO), sometimes termed *quicklime*, to distinguish it from the hydrate of lime or calcic hydrate (CaH_2O_2).

The use of lime in the mixtures called mortars and cements, also in hydraulic mortars, and for many other useful purposes, is well known. The salts of lime are far too numerous to be considered here. The most important are calcic carbonate ($CaCO_3$), calcic sulphate ($CaSO_4$), calcic phosphate (Ca_32PO_4), and calcic fluoride ($CaFl_2$).

STRONTIUM.

Symbol, Sr. Atomic weight, 87·5.

Another of the metals discovered by Davy in 1808, and so called because obtained from a mineral originally noticed by Dr. Hope, and called strontianite, the strontic or strontium carbonate ($SrCO_3$).

It is a yellow metal, having a specific gravity of 2·54, which is malleable, and has a certain amount of tenacity, and burns, when heated in the air, with a crimson flame emitting sparks. It decomposes water. The only oxide is strontia (SrO). The most important salt is strontic nitrate (Sr_2NO_3), now

used extensively in all pyrotechnic displays in consequence of the marked red which it imparts to flame. The other important salts, both of which occur native, are strontic carbonate ($SrCO_3$), and strontic sulphate ($SrSO_4$).

BARIUM.

Symbol, Ba. Atomic weight, 137.

There is a mineral called "heavy spar," containing baryten, so called from βαρύς (heavy); it is a sulphate of barium or baric sulphate ($BaSO_4$), and it has given the name to this metal. Discovered, like the preceding ones of this class, by Davy, in 1808.

It is a pale yellow metal, the specific gravity of which has not yet been determined. Barium decomposes water and is quickly oxidized in the air. It forms two oxides: baryta or baric oxide (BaO), and baric dioxide or peroxide of barium (BaO_2).

The chief salts are baric chloride or chloride of barium (BaC_2, $2H_2O$), baric sulphate ($BaSO_4$), which occurs native, and is used for adulterating white lead, and baric nitrate (Ba_2NO_3), used in common with the baric chloride as the chief test for sulphates. Baric nitrate is likewise employed in pyrotechnic mixtures to impart a green colour to the fire.

Baric carbonate ($BaCO_3$), occurs native, and is called *witherite.*

The metals of this class all form insoluble carbonates, oxalates, sulphates, and phosphates.

CLASS III.

ALUMINIUM, GLUCINIUM, ZIRCONIUM, THORIUM, YTTRIUM, ERBIUM, CERIUM, LANTHANUM, DIDYMIUM.

*Metals of the Earths.**

ALUMINIUM.

Symbol, Al. Atomic weight, 27·5.

Every kind of clay representing compounds of aluminium with silica, called scientifically hydrated aluminic silicate, whether it be common clay, pipeclay, blue clay, loam, or fire-clay, or the more valuable form called kaolin — the porcelain clay of china, or Cornish stone, yellow ochre, red bole, fullers' earth, —all contain this metal.

The perfect productions of Sévrès are said to be made of a composition consisting of

Washed kaolin	62 parts
Aumont sand	17 "
Quartz or feldspar	17 "
Bougival chalk	4 "

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* Of these, aluminium only will be considered, as the other metals of this class do not present features of any interest to the general reader.

The first step in the preparation of aluminium is the production of alum from the alum schist or alum ore found near Glasgow and at Whitby in Yorkshire; indeed, the metal is so called from *alumen*, clay, and was discovered by Davy in 1808. It is, however, from the aluminium chloride or chloride of aluminium (Al_2Cl_6) that the metal is usually procured.

The following is M. St. Claire Deville's process for obtaining this metal:

"Introduce into a glass tube of about an inch in diameter from 200 to 300 grammes of chloride of aluminium, closing the ends with a plug of asbestos;



FIG. 512.—*Sèvres Porcelain, French Exhibition*, 1867.

then conduct hydrogen gas, dry and perfectly free from atmospheric air, into the tube, and heat the chloride of aluminium in this current of gas by means of charcoal. This will have the effect of driving off the hydrochloric acid, chloride of silicium, and chloride of sulphur, with which it is always impregnated. Capsules of as large size as possible, containing each some grammes of sodium, previously crushed between two sheets of dry filter-paper, are then introduced into the glass tube. The tube being full of hydrogen, the sodium is melted; and the chloride of aluminiun, on being heated, will be distilled and decomposed with incandescence, which may be easily moderated. The operation will be complete when all the sodium has disappeared, and the chloride of sodium formed has absorbed a sufficient quantity of chloride of aluminium to saturate it. The aluminium will now exist in the state of a double chloride of aluminium and sodium, which is a very fusible and volatile compound. The capsules are next to be removed from the glass tube, and placed in a large porcelain tube furnished with a pipe leading to a receiver. Through this porcelain tube, while heated to a lively red heat, a current of hydrogen, dry and free from air, is caused to pass, and the chloride of alumi-

nium and sodium will be thereby distilled without decomposition, and collect in the receiver. After the operation all the aluminium will be found collected in the capsules in the form of large globules; these are washed in water, which will carry off a little of the salt produced by reaction, and also some brown silicium. In order to form a single mass of all these globules, after being cleansed and dried they are introduced into a capsule of porcelain, into which is put, as a flux, a small quantity of the product of the preceding operation—*i.e.*, of the double chloride of aluminium and sodium. On heating the capsule in a muffle to the temperature of about the melting-point of silver, all the globules will be seen to unite in a brilliant mass, which is allowed to cool, and then washed. The melted metal must be kept in a closed porcelain crucible until the vapours of the chloride of aluminium and sodium with which the metal is impregnated have entirely disappeared. The metallic mass will then be found surrounded by a light pellicle of alumina arising from the partial decomposition of the flux."

Messrs. Bell, of Newcastle, have perfected a convenient process, which works very admirably. They heat in a reverberatory furnace the double salt the sodio-aluminic chloride ($NaCl, AlCl_3$) with fluor spar or cryolite and metallic sodium; a very powerful action occurs, and large quantities of aluminium are obtained.

Aluminium is a white metal, very much like zinc, and is malleable and ductile: it can be rolled into sheets or drawn into wire, and, when cast into long bars and struck with a wooden rod, is very sonorous, the vibrations continuing for a considerable length of time after the blow is given.

Aluminium is remarkably light, having a specific gravity of only 2·6, so that it is rather more than two-and-a-half times heavier than water, and is therefore used for a great variety of useful and ornamental purposes where lightness is desirable.

The only oxide known is alumina (Al_2O_3), the basis of all clays, which in the native crystalline state is known in the form of corandum and emery, or the costly jewels, the ruby and sapphire. The specific gravity of the ruby is 3·95.

Alumina is one of the most valuable mordants known in the arts of dyeing and calico printing.

The most important salts of aluminium are aluminic chloride (Al_2Cl_6), aluminic sulphate ($Al_2 3SO_4$, $18H_2O$), and alum or potassio-aluminic sulphate (KAl_2SO_4, $12H_2O$). There are other varieties of alum obtained by substituting for the one atom of potassium an equivalent of sodium or ammonium; and if iron, chromium, or manganese are substituted for the aluminium, what is termed iron, chrome, and manganese alums are produced, of which one example may suffice,—iron alum (KFe_2SO_4, $12H_2O$). In this it will be noticed that Fe_2SO_4 is substituted for Al_2SO_4.

CLASS IV.
MAGNESIUM, ZINC, CADMIUM.
The Zinc Class.

MAGNESIUM.
Symbol, Mg. Atomic weight, 24·3.

Sea-water, many springs, but especially the mountain limestone or dolomite is to be regarded as the chief source of magnesium, so called because it was originally brought from Magnesia in Asia Minor. Magnesium has assumed an important position amongst the metals on account of its useful employment as a means of producing a brilliant artificial light. The manufacture and the uses of the metal have been so lately described in the "Mechanic's Magazine,"* that extracts from this thoroughly practical thesis will be given here.

"Magnesium was one of Sir Humphrey Davy's many discoveries. He proved, in 1808, with the galvanic battery of the Royal Society, that magnesia was a compound of a metal with oxygen,—in a word, was the ash of a burnt metal. The fact lay dormant for many years: a new entry was simply made in the catalogue of elements. Bussy, the Paris chemist, exhibited, about 1830, the metal in larger quantities than had yet been obtained: he treated magnesium chloride with potassium, when the potassium, combining with the chlorine, left the magnesium in the metallic state. There discovery again rested until about 1856, when Deville and Caron taught chemists how to procure the metal with greater ease by substituting sodium for potassium. Bunsen, of Heidelberg, and Roscoe, of Manchester, shortly after proclaimed its value as a source of light. Thus science did her work: it remained for practical skill to coin her hints into current commercial service. The matter was taken up at this point by Mr. Edward Sonstadt, a young Englishman with a name derived from Swedish ancestry. Why, he asked, should not the laboratory process of Deville and Caron be so far improved as to be capable of being worked on a large manufacturing scale? and resolved to devote his energies to the solution of the question. Happily, he succeeded. After upwards of a year's experimenting, he pursuaded some gentlemen to join him; a Company for the production of magnesium was formed, and business commenced in Manchester. The metallurgical process conducted on the Company's premises in Springfield Lane, Salford, is as follows:

"Lumps of rock magnesia (carbonate of magnesia) are placed in large jars, into which hydrochloric acid in aqueous solution is poured. Chemical action at once ensues: the chlorine and the magnesium embrace, and the oxygen and carbon pass off in the form of carbonic acid. The result is magnesium in combination with chlorine instead of with oxygen. The problem now is to dissolve this new alliance,—to get rid of the chlorine, and so obtain the magnesium. First the water must be evaporated, which would be easy enough if not attended with a peculiar danger. To get the magnesium chloride perfectly dry, it is necessary to bring it to a red heat; but this would result in the metal



FIG. 513.—*Magnesium Balloons at the Crystal Palace.*

dropping its novel acquaintance with chlorine and resuming its ancient union with oxygen. To avert this re-combination, the magnesium chloride, whilst yet in solution, is mixed with sodium chloride (*i.e.*, common salt) or potassium chloride, and, thus fortified, the aggressions of oxygen whilst drying are kept off. The mixture is exposed in broad open pans over stoves, and when sufficiently dry the double salt is scraped together and placed in an iron crucible, in which it is heated until melted, whereby the last traces of water are driven off; it is then stowed away until required in air-tight vessels to prevent deliquescence. Here comes in that curious metal, sodium, also discovered by Davy.

"Having, then, got together sodium and dry magnesium chloride, all is ready for the production of the desired metal. Five parts of the magnesium chloride (mixed, however, as we have noted, with sodium chloride) to one part of sodium, are deposited in a strong iron crucible with a closely-fitting lid, which is screwed down. The crucible is placed in a furnace and heated to redness. The contents are thus fused together, when the sodium takes the chlorine from the magnesium. The crucible is then lifted from the fire and allowed to cool. When the lid is removed, a solid mass is discovered, which, when tumbled out and broken up, reveals magnesium in nuggets of various sizes and shapes, bright as silver, and like eggs, buttons, nuts, and pin-heads, and also in minute granules and black powder; all which is carefully separated and collected from the dross. The magnesium in this condition contains various impurities, the worst of which is uncombined sodium. From these it is delivered by distillation. The crude metal is placed in a crucible, through the bottom of which a tube ascends to within an inch of the lid; the tube leads to an iron box placed beneath the bars of the furnace, so that it may be kept cool. The lid being carefully fixed, the atmospheric air, as containing

oxygen, is expelled by the injection of hydrogen, and as the crucible becomes heated the magnesium rises in vapour, descends the upright central tube, and condenses in purity in the box below; it is subsequently melted and cast in ingots.

"When the Magnesium Company commenced business, it was fancied that their product might be used in jewellery, but a little experience dissipated the illusion. A fresh surface of magnesium is little inferior in appearance to silver; but it soon contracts from the dampness of the atmosphere a coat of oxide, which is fatal to its beauty. Gradually the Company were brought to the conclusion that they must find their market in the use of the metal as a source of light. For this their commodity had high qualifications. Its power was unequalled save by the electric light, and it has a peculiar charm in displaying colours as in sunshine.

"At the meeting of the British Association in Nottingham, Mr. Larkin lighted up the large refreshment-tent, including a temporary garden, for two evenings with a couple of his lamps, and obviated the necessity of laying on gas; and his invention has since been exhibited and tested on several similar important occasions. He has also devised a portable lamp for surveyors of mines and explorers of subterranean and dark places, which received the approval of practical men. We are as yet at the beginning of the uses of the magnesium light: its only real rival in illuminating power is electricity, which, however, is not likely to compete with it on the score of handiness and portability. It is true, magnesium is at present a costly material: it is retailed in powder at 5*s.* per oz.—the price of silver; though, it is to be noted, an ounce of magnesium is six times the bulk of an ounce of silver. Moreover, the manufacturers assure us that as the consumption increases the price will fall. Probably some chemist will find out how to dispense with sodium in extracting it from the ore, or else how to obtain sodium more cheaply. The price of magnesium is ruled by that of sodium: all else connected with its working is of comparatively small importance. The qualities and merits of the magnesium light are now familiar to most people: these have been displayed with great effect by means of the balloons sent up from the Crystal Palace, with rockets attached primed with magnesium filings and chlorate of potash. The rockets, as they burn, illuminate the palace and the surrounding country with a radiance between sunshine and moonshine, and display the countenances and dresses of the gazing crowd, and the flowers and foliage of the garden, in the tints of daylight. For fireworks magnesium serves as an ingredient of surpassing brilliancy; the makers, however, complain that its very excellence is an objection, for those who see it once demand it always, to the prejudice of the commoner and less costly articles."

There is only one oxide of magnesium, viz., magnesia (MgO).

The important salts of this metal are magnesic chloride ($MgCl_2$), the source of the metal, magnesic sulphate or Epsom salts ($MgSO_4$, $7H_2O$), and magnesic carbonate ($MgCO_3$).

The magnesic silicates occur in nature, some of the most familiar being talc ($4MgO$, $5S_iO_2$), steatite, French chalk or soapstone, and meerschaum, or hydrated silicate of magnesia.

The phosphates of magnesium are important in analytical chemistry, the ammonio-magnesic phosphate (MgH_4N, PO_4, $6H_2O$) being the product obtained when solution of hydro-disodic phosphate, mixed with that of ammonium chloride, is added to one of a magnesic salt.

ZINC.

Symbol, Zn. Atomic weight, 65·2.

This metal, it is stated by Griffiths, "was first thus called in the writings of Paracelsus, about the year 1540. The term is probably derived from the German word *zinken*, signifying 'nails,' and applied to this metal on account of its frequently forming pointed particles somewhat resembling nails when melted and suddenly poured into water."



FIG. 514.—*Zinc Casting, French Exhibition*, 1867.

SOURCES WHENCE DERIVED.

It is obtained from the mines of Cornwall, Wales, Cumberland, and the Isle of Man, in the form of zincic sulphide (Blende or Black Jack), and zincic carbonate or calamine; is very abundant in England, and is found principally in the Mendip Hills and various parts of Somersetshire, at Holywell, Flintshire, at Castleton, Derbyshire, and in Cumberland.

In order to reduce the zincic sulphide or carbonate to the metallic state, the powdered ore is roasted or calcined, by which it loses about 20 per cent., and is converted into an oxide. It is then ground in a mill, and mixed with powdered coal, and strongly heated in large clay crucibles, so that, as the vapour of zinc is produced, it is distilled *per descensum*, and is condensed partly in powder and partly in irregular-shaped lumps, which fall into iron basins placed at the end of the pipe: this is constantly looked to, to prevent the zinc that distils over clogging it up. The crude metal is again melted and cast into ingots or sheets

Physical Properties.

Zinc presents a beautiful crystalline structure if a thick bar or slab is broken with a sledge-hammer; its colour is a bluish-white. In bending zinc for battery purposes, it is soon found that if the metal is heated to about 300° F., it is much more manageable and does not break, and thus in rolling the zinc the slabs are always previously heated to 212° or 300°; at a higher temperature it again becomes brittle, and melts at 773° F.

The specific gravity of zinc is 6·8 to 7·1. The "Building News," speaking with authority on the application of this metal to building and other purposes, says:

"This metal has been largely employed for pipes, for galvanic batteries used in working the electric telegraph, as a substitute for white lead, and as a constituent of brass and German silver.

"Zinc is, as is well known, largely obtained from Prussia; and we find that nearly 4,500,000 cwt. of zinc were obtained in 1857. In the seven large smelting establishments in Belgium and Prussia, belonging to the Vieille Montagne Company, there are 230 furnaces. Fifteen years ago the quantity of zinc used for roofing was not more than 5,000 tons; now, it appears, 23,000 tons of sheet zinc are annually made by this Company. For ship sheathing 3,500 tons are produced, although fifteen years ago zinc was not employed at all for this purpose. Stamped ornaments in zinc date only from 1852; now there are 1,500 tons produced for this object. For ships' sheathing zinc must necessarily be altogether free from impurity, or it will soon decay. But there can be no question about the usefulness of this metal for building purposes; and the fact that it is coming into still greater use and is becoming better known and appreciated is evidence that its reputation is increasing. With care in purchasing and laying there is but little doubt that it will turn out well. In Paris it has been used for nearly every roof formed for some years. The new markets, constructed of iron in 1856, have been covered with zinc, and, excepting in one place where the workmen were careless, the whole of the zinc is in capital condition. In Germany zinc for roofing is largely used, and the work is generally remarkable for solidity and closeness."

Chemical Properties.

At a bright red heat and when exposed to the air zinc is rapidly oxidized, and then takes fire, burning with a bright greenish flame, and forming the only oxide of this metal, viz., the zincic oxide (ZnO), or what was formerly called the "flos philosophorum" or philosopher's wool, and now termed zinc white.

The chief salts of zinc are zincic sulphate ($ZnSO_4$, $7H_2O$), also zincic chloride ($ZnCl_2$), used as a disinfectant under the name of "Burnett's Disinfecting Fluid." Zincic sulphide or blende (ZnS) and zincic carbonate or calamine ($ZnCO_3$) have already been spoken of as the natural compounds from which zinc is obtained.

CADMIUM.

Symbol, Cd. Atomic weight, 112.

This metal was discovered in the ore of zinc by Stromeyer in 1817. It has as pecific gravity of 8·6, is a white metal which fuses at 442°, and crystallizes in octohedral crystals.

Cadmic oxide or oxide of cadmium (CdO) is the only known oxide of this metal. Cadmic sulphide, chloride, and iodide are well-known salts of cadmium. The last-named, iodide, has already been mentioned in connection with the photographic art.

CLASS V.

IRON, MANGANESE, COBALT, NICKEL, CHROMIUM, URANIUM, INDIUM.

The Iron Class.

IRON.

Symbol, Fe (Ferrum). Atomic weight, 56.

SOURCES WHENCE DERIVED.

In an orbit peculiar to themselves are supposed to revolve countless fragments of a solid nature, varying in weight from tons to pounds, ounces, and grains or mere dust: these bodies are called asteroids or planetary dust; and when they enter the atmosphere of the earth, they become ignited by friction in their very rapid movement through the upper portions of the air, and, when drawn within the sphere of the attraction of the earth, they fall into or upon our planet, and are then called "meteorites." These remarkable visitors contain a large proportion of pure metallic iron, also sulphur, phosphorus, carbon, manganese, magnesium, nickel, cobalt, tin, and copper.

Metallic iron in small quantities has been found associated with the ores of platinum. The ores of this metal are, however, legion, and amongst the most important are iron pyrites (FeS_2); clay ironstone, an impure carbonate, and the source of nearly all the enormous quantities of iron made in Great Britain; the hæmatites, red and brown (the former Fe_2O_3, the latter $2Fe_2O_3$, $3H_2O$); specular iron ore (also Fe_2O_3); and the magnetic iron ore or loadstone (FeO, F_2O_3).

The smelting of iron ore is a process which has been brought to the highest degree of perfection in this country; it is, therefore, interesting to notice first the more primitive and ancient method of reducing iron ore to the metallic state, such as that illustrated in Fig. 515, and carried on by the natives in India.

"*Smelting of Iron Ore in Kasya Hills.*—The following is the method pursued from time immemorial by the natives of this part of the country in working down the ores of iron so plentifully met with hereby. There are large grass huts at least 25 ft. high, the thatch of which reaches down to the ground on all sides; the interior, of an oval form, 15 by 30 ft. in the two diameters, is divided into three apartments, the central one being the smelting-room. Two large double bellows, with the nozzles pointed downwards, are set up on one side of the apartment, on the upper side of which a man stands with one foot on each, his back supported by two planks. He holds a stick in his left hand, which is suspended from the roof, and has two straps attached to it below, connected with the two bellows: these are worked quickly by a wriggling motion of the loins and the strength of the leg. The nozzles of the bellows unite in a tube which leads underground, from a sort of wind-chest, to the hearth,

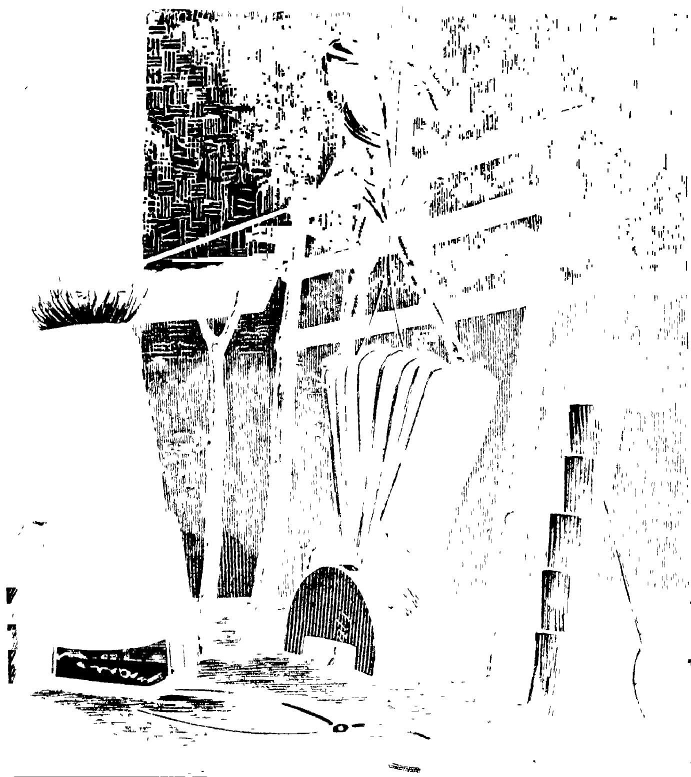


FIG. 515.—*Smelting Iron Ore in India.*

about four feet in front of them. Over the hearth is a chimney of pipeclay, braced with iron hoops, 2 ft. in diameter at the bottom and about 6 ft. high; the mouth at the bottom is on the side away from the bellows, and the chimney inclined from them, to direct the heated air from the smelter towards an opening in the roof. At the right side of the bellows, and even with the top of the chimney, is a trough containing damp charcoal and ironsand. At every motion of his body the operator with a long spoon tumbles a piece of this charcoal, with the ironsand adhering to it, down the funnel of the furnace; and when a mass of melted—or rather softened—iron is formed on the hearth, it is

taken out with the tongs, and beaten with a heavy wooden mallet on a large stone by way of anvil. The iron in this state is sent down to the plains for sale or barter."*

Herodotus tells us that amongst the most precious gifts presented by the Indian monarch Porus to Alexander the Great was a pound of steel, the value of which at that period, according to a rough calculation of the elder Mushet, may be estimated at about £40. A pound of steel, at present prices of £14 a ton, costs, within a fraction, three-halfpence of our money. That the manufacture of steel was in later ages carried to great perfection in India, as well as in the South of Europe, especially in its application to warlike instruments, as swords, spear-heads, daggers, and the like, we have abundant evidence in specimens of ancient art.

In commerce iron is known and used in three different conditions, viz., cast iron, wrought iron, and steel. Each of these forms exhibits special physical properties, and all differ essentially in their chemical constitution.

As a contrast to the ancient method of smelting iron ore in India, we have in England the immense "blast furnace," 50 ft. high and from 14 to 17 ft. in diameter. The crude materials are roasted clay ironstone, coal, and limestone: these, with the assistance of a powerful blast of air, react on each other: the carbon deoxidizes the oxide of iron, and the limestone is the flux which melts with and carries off the earthy matter. The iron falls down and collects in what is called the crucible or hearth, and is run into rough sand moulds, and when cold is called "pig" or "cast" iron.

By the last official returns, taken from Hunt, the total quantity of iron ore raised in the United Kingdom, in 1867, amounted to 10,021,058 tons 9 cwt., the estimated value of which was £3,210,098 0*s*. 4*d*. Foreign ores imported, 86,568 tons. Total quantity of iron ore converted into pig iron, 10,107,626 tons. The number of furnaces in blast were 551½.

Pig iron produced:	Tons.
In England	2,810.946½
„ Wales	919,077
„ Scotland	1,031,000
Total production of pig iron in Great Britain	4,761,023½

This quantity, estimated at the mean average cost at the place of production, would have a value of £11,902,557. Into this large amount of ore Northamptonshire enters for 416,765 tons, of the estimated value of £104,191; and the North Riding of Yorkshire, or the Cleveland district, produced 2,739,033 tons, of the estimated value of £798,056. The total produce of iron ore in Scotland in the same year was 1,264,800 tons, of the estimated value of £311,200, both returns being less than the corresponding returns of the preceding year. Such are the most recent returns of a manufacture which gives direct employment to 250,000 persons, and the prosperity of which, or the reverse, affects the comforts or privations of so many thousands of our fellow-countrymen.

Pig or crude cast iron contains many foreign bodies which interfere with its use for purposes where tough, good iron is required. There are three varieties of cast iron, viz., grey, mottled, and white cast iron. They contain combined

* "Journal of the Asiatic Society," Vol. I. 1832.

carbon, graphite diffused through the metal, silicon, sulphur, phosphorus, iron, manganese, and sometimes, though rarely, copper, arsenic, cobalt, and chromium. To free the iron from these impurities, Mr. Cort invented and carried out the process of "puddling" iron, by which the carbon and other bodies were almost wholly taken out of the pig iron, and "wrought" or nearly pure iron obtained.

To convert wrought iron into steel, the carbon is again united by the tedious and costly process called "cementation," the "bar" or "wrought" iron being kept for some three weeks in a furnace surrounded with charcoal, until it has absorbed a sufficient quantity of solid carbon.

The most remarkable improvement in the manufacture of pig iron direct into wrought iron or into steel is undoubtedly that of Mr. Bessemer. The author of a very clever pamphlet on "Heaton's Process for the Treatment of Cast Iron in the Manufacture of Steel" (to be described presently), thus speaks of it:

"The enthusiasm with which the Bessemer process was welcomed in all parts of the world, in the year 1855, is still fresh in the recollection of all taking an interest in the iron trade. The invention excited a kind of frenzy. The very site where the experiments had been carried on derived fresh interest from the event. On the spot where Richard Baxter tried to save men's souls from fire eternal, Bessemer had studied as earnestly to save their bodies from fire temporal. The "heel-piece" for the "limping sinner" was replaced by the crucible for the sweating puddler. The making of iron bars, up to that time an operation of four successive fires, was now performed by one heat. After the melted iron had run out of the pig-producing furnace, the usual process had been to stir it by human labour, with a view to expose all parts of its interior and exterior to the action of the atmosphere, in order that the carbon, and other extraneous matter, might be burnt out by the aid of oxygen. Mr. Bessemer substituted for this the forcing of air by steam power through the molten metal. Thus, without any additional fuel in the furnace, the heat of the iron was not only kept up, but increased by the combustion of the oxygen mixing with the carbon in the interior of the molten metal, and the iron was rendered malleable, ready for the tilt-hammer, at a single heat."

After burning out the carbon and silicon from the pig iron—usually Lancashire hæmatite pig—the Bessemer steel is made by adding to the melted wrought iron such a quantity of pure cast iron as is necessary to give carbon enough to convert the whole mass into steel. The cast iron added usually contains 6 per cent. of carbon and 10 of manganese, and directly after it is added the steel is cast into ingots. Moreover, the whole process is carefully watched with the spectroscope, so that the person who directs the operations knows exactly, by the lines obtained from the flame of the furnace, when the carbon and silicon are burnt out, and the precise moment when the pure cast iron should be added. In this manner six tons of cast iron are converted into steel in twenty minutes.

It would be thought that such a process could not be surpassed; but the author of the pamphlet already referred to thus speaks of the rival process described by Mr. Heaton:

"It is at the Langley Mill Steel Works that Mr. Heaton has successfully developed the process which he has patented, which is one remarkably simple in practical working.

"An ordinary cupola furnace is charged with pig iron and coke, and fired

in the usual way, and the iron when melted is drawn off into a ladle, from which it is transferred to the converter.

"The converter is a wrought-iron pot lined with fire-brick. In the bottom is introduced a charge of crude nitrate of soda, usually in the proportion of 2 cwt. per ton of converted steel, usually but not invariably diluted with about 25 lbs. of siliceous sand. This charge is protected or covered over with a close-fitting perforated iron plate weighing about 100 lbs., the diameter of the plate being about 2 ft. The converter, with its contents, is then securely attached, by movable iron clamps, to the open mouth of a sheet-iron chimney, also lined for 6 ft. with fire-brick, and the melted iron, taken in a crane ladle from the cupola, is poured in. The subsequent part of the process is thus described by Professor Miller, of King's College, Vice-President of the Royal Society and Assayer to the Mint.

"'In about two minutes,' writes the Professor in his preliminary report, dated the 14th of October, 'a reaction commenced. At first a moderate quantity of brown nitrous fumes escaped; these were followed by copious blackish, then grey, then whitish fumes, produced by the escape of steam, carrying with it in suspension a portion of the flux After the lapse of five or six minutes, a violent deflagration occurred, attended with a loud roaring noise and a burst of a brilliant yellow flame from the top of the chimney. This lasted for about 1½ minutes, and then subsided as rapidly as it commenced. When all had become tranquil, the converter was detached from the chimney, and its contents were emptied on to the iron pavement of the foundry.

"'The crude steel was in a pasty state and the slag fluid; the cast-iron perforated plate, which was placed as a cover to the converter, had become melted up and incorporated with the charge of molten metal. The slag had a glassy or blebby appearance, and a dark or green colour in mass.'

"Professor Miller proceeds to detail the subsequent parts of the process, and the results of his analysis of some of the products.

"'A mass of crude steel from the converter was then subjected to the hammer. About 4½ cwt. of the crude steel was transferred to an empty but hot reverberatory furnace, where in about an hour's time it was converted into four blooms, each of which was hammered, rolled into square bars, cut up, passed through a heating furnace, and rolled into rod, varying in thickness from 1 in. to five-eighths of an inch.

"'Three or four cwt. of the crude steel from the converter was transferred to a re-heating furnace, then hammered into flat cakes, which, when cold, were broken up and sorted by hand for the steel melter.

"'Two fire-clay pots, charged with a little clean sand, were heated, and into each 42 lbs. of the cake steel was charged; in about six hours the melted metal was cast into an ingot.

"Two other similar pots were charged with 35 lbs. of the same cake steel, 7 lbs. of scrap steel, and 1 oz. of oxide of manganese. These also were poured into ingots. The steel was subsequently tilted, but was softer than was anticipated.

"'These results on the whole are to be considered rather as experimental than as average working samples. I have, therefore, made an examination of the following samples only: No. 4, Crude Cupola Pig: No. 7, Hammered Crude Steel; No. 8, Rolled Steely Iron; No. 5, Slag from the converter.

"'I shall first give the result of my analysis of the three samples of metal:

	Cupola. Pig (4).	Crude. Steel (7).	Steel-Iron (8).
Carbon	2·830	1·800	0·993
Silicon, with a little titanium	2·950	0·266	0·149
Sulphur	0·113	0·018	traces
Phosphorus	1·455	0·298	0·292
Arsenic	0·041	0·039	0·024
Manganese	0·318	0·090	0·088
Calcium	—	0·319	0·310
Sodium	—	0·144	traces
Iron (by difference)	92·293	97·026	98·144
	100·000	100·000	100·000

"'It will be obvious from a comparison of these results that the reaction with the nitrate of soda has removed a large proportion of the carbon, silicon, and phosphorus, as well as most of the sulphur. The quantity of phosphorus (0·298 per cent.) retained by the sample of crude steel from the converter which I analysed, is obviously not such as to injure the quality.*

"'The bar-iron was in our presence subjected to many severe tests. It was bent and hammered sharply round without cracking. It was forged and subjected to a similar trial, both at a dull red and a cherry red heat, without cracking; it also welded satisfactorily.

"'The removal of the silicon is also a marked result of the action of the nitrate.

"'It is obvious that the practical point to be attended to is to procure results which *shall be uniform*, so as to give steel of uniform quality when pig of similar composition is subjected to the process. The experiments of Mr. Kirkaldy on the tensile strength of various specimens afford strong evidence that such uniformity is attainable.

"'I have not thought it necessary to make a *complete* analysis of the slag, but have determined the quantity of sand, silica, phosphoric and sulphuric acid, as well as the amount of iron, which it contains. It was less soluble in water than I had been led to expect, and it has not deliquesced though left in a paper parcel.

"'I found that of 100 parts of the finely-powdered slag, 11·9 were soluble in water. The following was the result of my analysis:

Sand	47·3
Silica, in combination	6·1
Phosphoric acid	6·8
Sulphuric acid	1·1
Iron (a good deal of it as metal)	12·6
Soda and lime †	26·1
	100·0

"'This result shows that a large proportion of phosphorus is extracted by

* It is important to point out that as no analysis of the finished steel tested by Mr. Kirkaldy is given, it is not improbable that this small per centage of phosphorus might have been still further reduced before it arrived at its final state of manufacture.

† The use of lime was exceptional Its use is now discontinued; but its use on that occasion no doubt accounted for the slag being less deliquescent and soluble than it is usually found to be.

the oxidizing influence of the nitrate, and that a certain amount of the iron is mechanically diffused through the slag.

"'The proportion of slag to the yield of crude steel-iron was not ascertained by direct experiment; but, calculating from the materials employed, its maximum amount could not have exceeded 23 per cent. of the weight of the charge of molten metal. Consequently, the 12·6 per cent. of iron in the slag would not be more than 3 per cent. of the iron operated on.

"'In conclusion, I have no hesitation in stating that Heaton's process is based upon correct chemical principles: the mode of attaining the result is both simple and rapid. The nitric acid of the nitrate in this operation imparts oxygen to the impurities always present in cast iron, converting them into compounds which combine with the sodium; and these are removed with the sodium in the slag. This action of the sodium is one of the peculiar features of the process, and gives it an advantage over the oxidizing methods in common use.'

"The slag produced is already utilized at the works, and forms the subject of a new and valuable patent. There is every reason to believe that the products of combustion may, by the means of a mechanical arrangement devised by Mr. Heaton, be further utilized, and afford a large set-off on the original cost of the nitrate. It is also a great question whether the phosphorus may not be most profitably reduced from the slag for commercial purposes."

Physical Properties of Iron.

Pure iron has a bright white colour; though soft, it possesses great tenacity and toughness, and has a specific gravity of 7·844. It crystallizes in cubes, and, when made sufficiently hot, possesses the valuable property of cohering to another piece of iron, or what is termed "welding," when two clean hot surfaces are hammered together. Iron possesses in the highest degree the valuable properties of malleability, ductility, and tenacity, and has a curious susceptibility to magnetism.

Chemical Properties.

Iron takes fire and burns in air, or still better in oxygen, and if obtained in the state of powder by reducing ferric oxide (Fe_2O_3) at a low red heat by hydrogen, it takes fire spontaneously when shaken into the air.

There are four definite oxides of iron, viz.—

Ferrous oxide or protoxide	FeO
Ferric oxide or sesquioxide	Fe_2O_3
The black oxide or magnetic oxide	Fe_3O_4
Ferric acid, not isolated, and known only in combination	H_2FeO_4

Amongst the chief salts of iron may be noticed ferrous sulphide (FeS), and ferric disulphide, the "iron pyrites" of nature (FeS_2); also the chlorides, iodides, and bromides of iron; ferrous carbonate and the silicates of iron; potassic ferro-cyanide or yellow prussiate of potash, and potassic ferri-cyanide or red prussiate, yielding, with a neutral or acid solution of a ferrous salt, "Prussian blue" (Fe_32FeCy_6, xH_2O)

MANGANESE.

Symbol, Mn. Atomic weight, 55.

A metal discovered by Gahn in 1775 in an ore examined by Scheele, and called by the latter manganese; but why he gave it that name is known only Swedish etymology.

The most important source of this metal is the natural mineral called the black oxide of manganese (MnO_2), used so largely for making oxygen gas and chlorine, and likewise employed to impart a purple colour to glass.

Manganese is a greyish-white metal, having a specific gravity of 8·013, and, although brittle, is hard enough to scratch steel. It decomposes water slowly, and can only be preserved in the metallic state (like potassium) by immersing it in Persian naphtha. It is feebly magnetic, and is said to exhale a peculiar odour when handled. There are various oxides of this metal:

Manganous oxide or protoxide	MnO
Manganic oxide or sesquioxide	Mn_2O_3
Mangano-manganic oxide or red oxide . . .	Mn_3O_4
Manganese dioxide or black oxide	MnO_2

Also two other compounds of oxygen and manganese, known only in combination as salts, viz.—

Potassic manganate	K_2MnO_4
Potassic permanganate	$KMnO_4$

The latter salts are now largely employed as disinfectants, because they have the power of oxidizing organic matter, and for that reason are used in certain processes as bleaching agents. The salts of manganese are too numerous to discuss here.

COBALT.

Symbol, Co. Atomic weight, 58·7.

This metal was discovered by Brandt in 1733, and was so named after a sprite or spirit that greatly troubled the miners in the German mines, and called by them *kobold*. It is a rare metal, reddish-white, and having a specific gravity of 8·5. Cobalt is extremely infusible, and, like iron in many respects, is also very tenacious and magnetic.

There are two oxides of cobalt:

Cobaltous oxide or protoxide . . .	CoO
Cobaltic oxide or sesquioxide . . .	Co_2O_3

The protoxide is a valuable article in commerce, because it is used to impart the blue colour to porcelain and pottery, and when combined with glass is called smalt, a lovely blue used largely by paper-stainers. Cobalt is easily recognized by the blue colour it imparts to borax in the oxidating flame of the blowpipe.

The important salts are the sulphide, chloride, sulphate, nitrate, and carbonate of cobalt.

NICKEL.

Symbol, Ni. Atomic weight, 58·7.

The so-called "false copper," or "*kupfer nickel*" of the German miners, has given the name to this metal, discovered by Cronstedt in 1751. This mineral is an arsenide of nickel (NiAs), and contains 44 parts of nickel and 56 of arsenic. "Speiss" is an impure arsenio-sulphide of nickel. Nickel is largely made and used in Birmingham in the manufacture of "German silver," an alloy of 18·4 nickel, 30·6 zinc, and 51 copper. Nickel is a white metal, having a specific gravity of 8·82. Although hard, it is both malleable and ductile, and, like the other metals belonging to this class, is feebly magnetic, losing that power entirely at 626° F.

There are two oxides of nickel,—the protoxide (NiO) and the sesquioxide (Ni_2O_3). The chief compounds of this metal are the sulphide of nickel, also nickel chloride, sulphate, and carbonate.

The salts of nickel impart a reddish-yellow colour to borax fused in the oxidating flame of the blowpipe.

CHROMIUM.

Symbol, Cr. Atomic weight, 52·5.

The name of this metal—taken from the Greek χρωμα, colour—is very suggestive of its important use in the preparation of certain pigments and in calico printing. This metal was discovered by Vauquelin in plumbic chromate in 1797. The most important ore containing it is the chrome iron-stone (FeO, Cr_2O_3), found chiefly in Sweden and North America. Chromium is very infusible, perhaps the most so of all the metals, and it has a specific gravity of 6·81.

There are four compounds of chromium and oxygen, of which the sesquioxide is the most valuable, whilst the chromates are largely used in the manufacture of pigments, &c.

Chromous oxide or protoxide of chromium . .	CrO
Chromic sesquioxide	Cr_2O_3
Chromo-chromic oxide	CrO, Cr_2O_3
Chromic trioxide or chromic acid . . .	CrO_3

The chief salts are the chromates, chromic chloride, sulphate, and nitrate.

URANIUM.

Symbol, U. Atomic weight, 120.

In the same year that Klaproth discovered this metal—viz., in 1789—Herschel had discovered the planet which now bears the same name, and in honour of the discoverer of the new planet the distinguished chemist gave it the name of uranium. The mineral called pitchblende contains nearly 80 per cent. of the black uranium oxide (2UO, U_2O_3); it also constitutes a part of the two minerals termed chalcolite and uranite or hydrated calcic diuranic phosphate.

Uranium is described as a steel-white metal, analogous in its chemical re-

lations to iron and manganese. There are two well-marked oxides, uranous oxide or protoxide (UO), and uranic oxide or sesquioxide (U_2O_3).

The salts of uranium are green, such as the chlorides U_2Cl_3 and UCl.

The chief use of this metal is in glass staining, the uranous oxide imparting a perfect black, and the uranic oxide a yellow, which shines most curiously in light containing Stokes's rays, or in those that exist beyond the extreme violet.

INDIUM.

Symbol, In. Atomic weight, 74.

Discovered by Reich and Richter in zinc blende, from the peculiar lines obtained by heating this substance in the Bunsen flame, and then viewing it with the spectroscope. Two bright lines were seen in the blue and indigo rays of the spectrum, not coincident with any other known element. It is stated to be a white malleable metal, having a specific gravity of about 7·36, and is easily fusible.

Indic oxide is white. A yellow sulphide and a white chloride or acetate of indium have already been obtained and experimented with.

CLASS VI.

TIN, TITANIUM, NIOBIUM, TANTALUM.

The Tin Class.

TIN.

Symbol, Sn (Stannum). Atomic weight, 118.

This metal appears to have been known from the earliest periods, and is even mentioned in the books of Moses. Fig. 516 will remind the reader that it is chiefly obtained from Cornwall and Devonshire, from the ore called *tin-stone*, stannic oxide or binoxide of tin (SnO_2). Tin is a yellowish-white metal, having a specific gravity of 7·292: it is malleable, and is sold in sheets called "tin foil," used largely with mercury in the silvering of looking-glasses.

The alloys of tin are very important. Tinned iron or tin plate, Britannia metal, solder, speculum, bell and gun metal, and bronze are all illustrative of its importance in the metallurgical arts.

There are two principal oxides of tin, viz., stannous oxide or protoxide of tin (SnO), stannic oxide or binoxide of tin (SnO_2). Stannic sulphide or mosaic gold, and the chlorides of tin are valuable compounds used in decorating, and as a mordant by the dyer and calico printer.

TITANIUM (symbol, Ti, atomic weight, 50),
NIOBIUM, and
TANTALUM
are very rare metals, which need not be described here.



FIG. 516.—*A Tin-Mine in Cornwall.*

CLASS VII.

MOLYBDENUM, VANADIUM, TUNGSTEN.

The Tungsten Class.

TUNGSTEN.

Symbol, W (Wolfram). Atomic weight, 184.

The only metal of this class that specially deserves attention (the other two being extremely rare) is tungsten. It is a greyish-black powder, which becomes brilliant if burnished, and has a specific gravity of 17·6.

There are two oxides, the dioxide (WO_2) and tungsten trioxide (WO_3).

Tungsten is sometimes employed in the manufacture of steel, to which it is said to impart a peculiar toughness.

CLASS VIII.

ARSENIC, ANTIMONY, BISMUTH.

These metals have already been described (see pages 609—616).

CLASS IX.
LEAD, THALLIUM.
The Lead Class.

LEAD.
Symbol, Pb (Plumbum). Atomic weight, 207.

Lead ore is very abundant in various parts of England: the chief ore is the native plumbic sulphide, protosulphide of lead, or *galena* (PbS). Lead is a bluish-white metal, having a specific gravity of 11·36: it marks paper, and is so soft that it is easily indented with the nail. It is malleable, ductile, and sufficiently tenacious for the purposes to which it is applied. It is easily melted, and fuses at a temperature of 620° F., and is most extensively used for making leaden pipes, cisterns, and for the gutter-work and covering of houses. Type, pewter, Britannia and Queen's metals, all contain lead. The red oxide is used in glass-making, and the carbonate and chromates, with the oxychlorides of lead, are largely employed as pigments.

Lead is the usual messenger of death in modern battles, and receives one of its most destructive forms in the Sneider bullet, which, with its cartridge and self-exploding arrangement attached, is shown at Fig. 517.

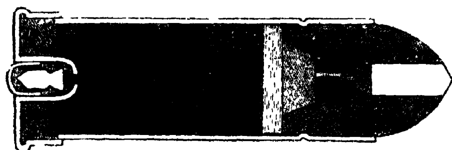


FIG. 517.—*The Sneider Cartridge.*

The terrible slaughter of the army of King Theodorus in the battle that preceded the fall of Magdala was due to the mistake the King made in exciting his troops to attack what he thought were baggage-mules, but which were, in fact, steel guns and rocket batteries. His men, crowded together, were shot down by hundreds. From the Sneider bullets and shells the Abyssinians received the most frightful wounds, and some were discovered after the battle with half their skulls blown off.

There are four oxides of lead: a black suboxide (Pb_2O), plumbic oxide or protoxide of lead (PbO), plumbic dioxide or peroxide of lead (PbO_2), minium or red lead (PbO, PbO_2). The sulphide, chloride, oxychloride, and the carbonates of lead represent the most valuable salts of this metal.

THALLIUM.
Symbol, Tl. Atomic weight, 204.

This metal was discovered by Mr. Crookes, the editor of the "Chemical News," who describes his discovery as strictly analogous to that of selenium



FIG. 518.—*The use of the Sneider Rifle in the Battle that preceded the fall of Magdala.*
After a picture by Mr. Baines.

by Berzelius. The observation of a brilliant green line by spectrum analysis in the dust from a pyrites burner led Mr. Crookes to the discovery of this metal, so called from the Greek θαλλος (a green tinge), on account of the magnificent green which it communicates to a flame.

Thallium is very soft, in fact it is the softest known heavy metal, being only exceeded in this respect by the alkali metals. A piece of lead scratches it with the utmost facility, without itself receiving an appreciable impression. It also possesses the property of welding together in the cold by pressure.

For all the interesting facts respecting this new metal the reader is referred to Mr. Crookes's lecture "On the Discovery of the Metal Thallium,"* delivered at the Royal Institution, also to the various papers written by the discoverer in the "Chemical News."

* Royal Institution of Great Britain, Friday evening, March 27, 1863. A lecture by William Crookes, "On the Discovery of the Metal Thallium." Pardon, Printer, Paternoster Row.

CLASS X.

COPPER, MERCURY, AND SILVER.

The Silver Class.

SILVER.

Symbol, Ag (Argentum). Atomic weight, 108.

Silver is another of the metals well known and appreciated by the ancients. It is sometimes met with in the native state, but is more generally associated with lead as argentic sulphide. By Pattinson's admirable process the pure lead is crystallized out of the alloy of lead and silver obtained by smelting lead ores containing a certain quantity of silver, and then, by "cupellation," the silver is obtained pure.

Any specimen of lead or galena supposed to contain silver is first powdered, weighed, and then well mixed with twice its weight of sodic carbonate,

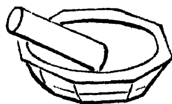


FIG. 519.—*Agate Pestle and Mortar.*

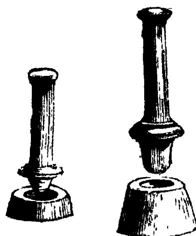


FIG. 520.

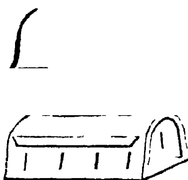


FIG. 521.—*Muffles.*

and 8 per cent. of powdered charcoal. This mixture is placed into a crucible sufficiently large, and gradually heated till the boiling up of the materials ceases, when the heat is urged quickly to a bright redness, and the crucible is then removed and allowed to cool. The button of lead is now placed on a "cupel," made with damp bone-ash compressed into a proper mould (Fig. 520). When the cupel is made it is easily pushed out of the mould and dried. The cupel is now placed in a muffle (Fig. 521), which is made of the same material as the best crucibles. The muffle is, of course, previously heated in a proper furnace, of which most useful examples are given in the cut Fig. 522.

By the proper management of the heat, the lead is oxidized, and sinks into the pores of the cupel, and at last a tiny bead of silver is apparent, which is taken out of the cupel when cold, and weighed.

Silver is a reddish-white metal, and possesses all the best physical properties of a metal, viz., malleability, ductility, and tenacity. It has a specific gravity of 10·53, and melts at 1,873° F. When heated in a small cup or crucible of charcoal in the voltaic arc, it volatilizes, and the hot vapour emits a light, which, passed through prisms, affords two bright green lines (see frontispiece), very characteristic of the presence of this metal.

Pure silver, instead of having, like palladium, potassium, and mercury, the property of absorbing hydrogen, prefers its usual companion, oxygen, and is said to take up, whilst in the liquid state, twenty-two times its bulk of this element. The metal gives out the oxygen when it assumes the solid state.

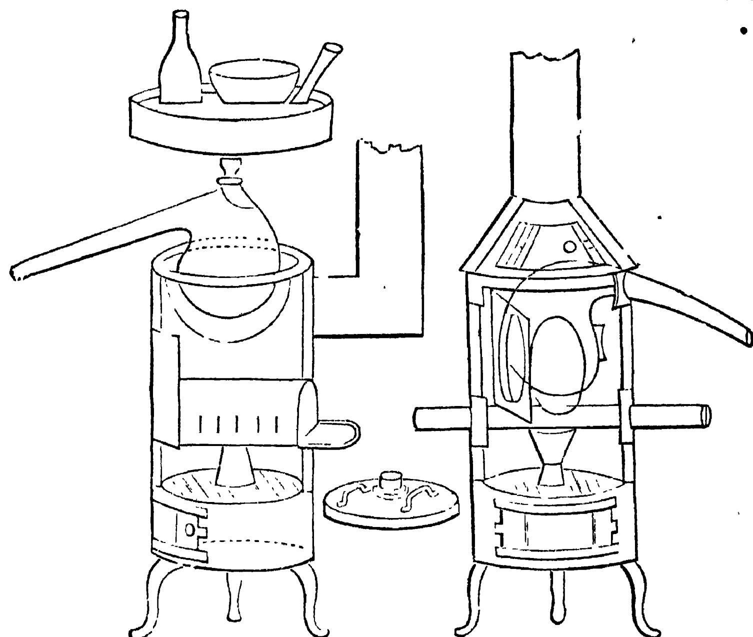


FIG. 522.—*Furnaces, for assaying Silver and Gold.*

A, furnace arranged with muffles, sand bath above, and retort; B, furnace, with earthen retort, and tube for other experiments. These furnaces are made of sheet iron, lined with fire-clay, and are sold by How, Foster Lane, City.

There are three oxides of silver:

Argentous oxide or suboxide of silver .	Ag_4O
Argentic oxide or protoxide of silver .	Ag_2O
Argentic peroxide	Ag_2O_2

The argentic sulphide (Ag_2S) is the mineral which yields the largest proportion of silver. The chloride of silver is an important body; there is a sub-chloride (Ag_2Cl), but the symbol of the former, called argentic chloride, is AgCl.

In the assay of silver by the wet process, the determination of the real quantity of the metal in any given specimen is brought within an error of ·5 in 1,000, whilst cupellation may vary, even in the most experienced hands, as much as 2 in 1,000. The solution of the alloy is tested by a measured quantity of a standard solution of sodic chloride (common salt); and this test, or that of hydrochloric acid, is so delicate that it will detect one part of silver in 200,000 parts of water. The chloride of silver settles to the bottom of the vessel in which it is precipitated and it may be

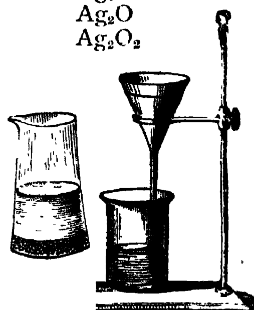


FIG. 523.—*Precipitating Glass for Argentic Chloride, with Funnel and Beaker Glass for filtering.*



FIG. 524—Elkington's Milton Shield.

collected, washed, dried, and weighed, to verify the standard solution of salt.

When exposed to the light, it gradually blackens, and hence is used for taking copies of negative photographs, the chloride which is not acted on by the light being subsequently dissolved out by a solution of hyposulphite of sodium. Zinc reduces the argentic chloride to the metallic state.

Argentic chloride is soluble in a solution of potassic cyanide, and is used for silvering. A better silvering solution is the argentic cyanide obtained by precipitating a solution of argentic nitrate with one of potassic cyanide, and dissolving the argentic cyanide in an excess of the potassic cyanide.

From either of these solutions of silver the most beautiful works of art are formed by precipitating the silver in moulds by a current of electricity.

FIG. 524 (pp. 646, 647) represents Messrs. Elkington and Co.'s magnificent Milton Shield.

This remarkable work of art in *repoussé* silver has since been purchased by the Government for the South Kensington Museum, and cost the firm nearly £3,000 to make. It received two gold medals at the Great French Exhibition, viz., one for the firm and one for the artist. The great firm of Elkington has now been established in Birmingham and London for many years, and has produced more than any other house those beautiful designs in silver which have raised the character of English silversmith's work to the highest pitch of eminence. Amongst the important works of art made by Messrs. Elkington since the Exhibition of 1862 are the following, all of which have received the highest encomiums from those capable of judging of art-work, to say nothing of the numerous medals awarded:

1867, Paris Exhibition: The Elcho Challenge Shield; the International Challenge Trophy; the Milton Shield (since purchased by the Government for the Kensington Museum); enamelled and silver-gilt baptismal gift from Her Majesty the Queen to the son of H.R.H. the Prince of Wales; bronze statue, 10 ft. 6 in. high, of H.R.H. the late Prince Consort, by W. Theed, Esq., erected at Balmoral; the bronze 8 ft. statues of Oliver Goldsmith and Edmund Burke, both by J. H. Foley, R.A., for the University of Dublin; and they are now proceeding with the four bronze statues, 7 ft. 6 in. high, each intended for the Holborn Viaduct.

There are other useful salts of silver, viz., argentic bromide ($AgBr$), argentic iodide (AgI), argentic fluoride (AgF), the argentic sulphate (Ag_2SO_4), and especially argentic nitrate ($AgNO_3$). The argentic phosphates are also worthy of notice.

COPPER.

Symbol, Cu (Cuprum). Atomic weight, 63·5.

Some years ago Professor Tennant, of the Strand, the celebrated mineralogist, deposited a great mass of very hard native copper from North America at the Polytechnic. In England the mines of Cornwall supply the clean copper ore which is smelted at Swansea. The process of roasting, melting and granulating, and gradually refining the metal, is very elaborate.

Copper is extremely malleable and ductile, and has a specific gravity of 8·921 to 8·952; it has a red colour, and emits a peculiar odour when handled. It is used in many different ways for coinage and the sheathing of ships, and is an important constituent of brass and other valuable alloys.

At the Great Exhibitions in this country and Paris, the copper trophies were always conspicuous objects; and the French especially now compete very closely with the English in the manufacture of those large copper vessels called "vacuum pans," used in sugar-boiling, of which the following, taken from Ure's Dictionary, is a good illustration.

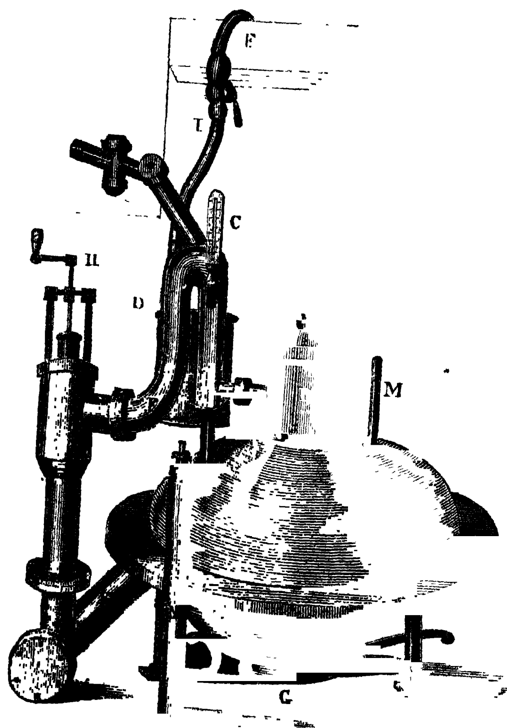


FIG. 525.

A, represents the vacuum spheroid; B, the neck, with the lid. From the side, B, a pipe passes into the lower extremity of the bent pipe, F; D, terminates in the pipe; E, valve connected with the vacuum main pipe, K; F, measure cistern; H, valve for cutting off supply; I, stop-cock; C, barometer, M, proof-stick; N, cistern pipe for excess syrup.

Copper does not oxidize in pure, dry, or moist air, and hence is used extensively in Moscow for covering the domes of churches. There are two oxides of copper, viz., cuprous oxide (Cu_2O), and cupric oxide (CuO). The chief salts of this metal are cupric sulphate ($CuSO_4$, $5H_2O$), cupric nitrate (Cu_2NO_3, $6H_2O$), cupric sulphide (CuS), cupric carbonate, and hydrated dibasic carbonate or malachite (CuO, H_2O, $CuCO_3$), so plentiful in the Russian dominions. The art of electrotyping is also carried out by Messrs. Elkington with the greatest success, and the finest works in copper are executed by that house, the metal being deposited from the cupric sulphate by electricity.

MERCURY.

Symbol, Hg (Hydrargyrum). Atomic weight, 200.

The title hydrargyrum conferred on mercury, is derived from the Greek ὕδωρ (liquid), and ἄργυρον (silver) or quicksilver. It is sometimes found native, but is usually prepared from cinnabar, a mineral sulphide of mercury.

Mercury is a very brilliant metal, fluid at all ordinary temperatures, and having a specific gravity of 13·56. At all temperatures above 41° F. it volatilizes slightly; hence the danger to workmen using this metal either for silvering looking-glasses, or thermometer and barometer making.

Mercury freezes at — 37·9′ F., and is not tarnished by exposure to damp or dry air at ordinary temperatures.

There are two principal oxides, mercurous oxide or suboxide of mercury (Hg_2O), and mercuric oxide or red oxide of mercury (HgO). The most valuable salts of mercury are the native sulphides, the chlorides of mercury, mercurous chloride or calomel ($HgCl$), and mercuric chloride or corrosive sublimate ($HgCl_2$). The mercuric iodide, mercuric sulphate, and mercuric nitrate are some of a long list of mercurial salts presenting many interesting features.

CLASS XI.

GOLD, PLATINUM, PALLADIUM, RHODIUM, RUTHENIUM, IRIDIUM, OSMIUM.

The Gold Class.

PLATINUM.

Symbol, Pt. Atomic weight, 197·1.

It was the sagacity, the patience, and learning of the late Dr. Wollaston that overcame all the difficulties connected with the manipulation of the ore of platinum, and not only demonstrated how that metal was to be extracted from the mineral, but also invented a method by which the metal, originally in the form of powder, was gradually brought to the solid state, and rendered both malleable and ductile.

The name of the metal is derived from *platina* (little silver), and it was first obtained by Wood in 1741.

Platinum comes chiefly from the Ural Mountains, although some is obtained in Mexico and Brazil, likewise in California and Australia. It is tolerably hard, and has a specific gravity of 21·5. The colour of this metal is white, and when polished it exhibits considerable brilliancy. The ductility and tenacity of platinum have been compared to that of iron.

It is quite infusible by any ordinary furnace heat, but melts in the voltaic arc of a powerful battery; and when enclosed in a hollow made in a lump of pure lime, may be fused, according to the process of Deville and Debray, by the oxyhydrogen blowpipe.

Platinum is largely used for crucibles, tubes, evaporating-vessels required

for laboratory purposes. Platinum foil for batteries and analytical experiments on the small scale, and platinum wire, are indispensable. Large stills, usually gilt inside, are used for the concentration of oil of vitriol: the gilding of the still prevents the acid finding its way through the pores of the metal.

There are two oxides of platinum, the protoxide or platinous oxide (PtO) and platinic oxide, the dioxide (PtO_2); also two sulphides, PtS and PtS_2.

One of the most important salts of the chlorides is the platinic chloride, always spoken of in the old standard works as the bichloride, but now called the tetrachloride (PtC_4). By gently heating this salt, finely-divided metallic platinum or platinum black is obtained; or a solution of platinic chloride may be precipitated with ammonium chloride: the ammonic platinum chloride is collected, washed, dried, and heated red hot, and then forms a finely-divided porous mass called "spongy platinum," which becomes red hot immediately a jet of cold hydrogen gas is directed upon it, because its pores are always full of oxygen, and the two gases, by the intervention of the spongy platinum, unite and form water. This power of condensing gases upon its surface is a very curious property of finely-divided clean platinum. Platinum chloride is always used to determine quantitatively potassium or ammonium in analytical researches.

PALLADIUM and RHODIUM were discovered by Wollaston in the ore of platinum in the year 1803; IRIDIUM and OSMIUM by Tennant in the same year; RUTHENIUM by Claus in 1845. All these metals were discovered in the ore of platinum, and might have been known much earlier if the spectroscope had been in use in the time of Wollaston. The last metal, but certainly not the least in importance, is gold.

GOLD.

Symbol, Au (Aurum). Atomic weight, 196·6.

California and Australia are now only spoken of as modern Ophirs and the lands of gold. Peru, Brazil, Hungary, the Ural Mountains, and even Africa, hide their diminished heads before the first-named countries, although it was from these countries that gold was chiefly obtained up to within the last twenty-five years.

Gold is found in the native state in various forms, sometimes crystallized in octohedral cubes, or tetrahedra occasionally in thin plates, stringy and arborescent, and in irregular lumps called "nuggets;" indeed, the latter title has become a household word, and the expression "he has found a nugget" amounts to an announcement of sudden good fortune.

The colour of gold (a full, rich yellow) is known to all. The specific gravity of this precious metal is 19·34. Gold is too soft to be used alone, and is, therefore, usually alloyed with copper. It takes very high rank in the properties of malleability, ductility, and tenacity. Gold melts at a temperature of 2,016° F., and any day, at the Polytechnic, may be seen the conversion of gold wire into a purple smoke by the discharge of the Leyden battery, showing the remarkable division of particles of which this and other metals are capable.

The true solvent of gold is nitro-muriatic acid (*aqua regia*); and after evaporating the solution, the auric chloride is obtained; this, re-dissolved in plenty of water and filtered to get rid of any argentic chloride, is precipitated

with a solution of ferrous sulphate. The gold gradually settles to the bottom of the vessel, and looks like brown mud by reflected, but purple by transmitted, light. The liquid may be poured off, and more water added; the finely-divided gold is then boiled two or three times with hydrochloric acid, and finally, being washed and dried, may be melted in a crucible under borax, or, better still, hydropotassic sulphate.

Gold is used for various ornamental purposes, either spread over other substances, as in the art of gilding, or employed to impart a magnificent ruby red to glass. Perhaps one of the best illustrations of the ingenious use of this metal is in the fabrication of ornaments for the person.

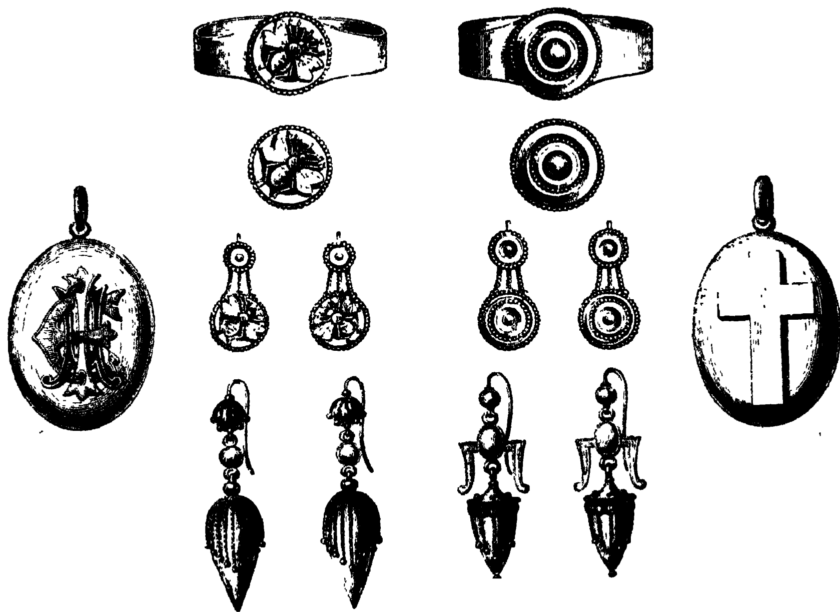


FIG. 526.—*Specimens of Streeter's Machine-made Jewellery of 18-carat Gold.*

In a little work entitled "Hints to Purchasers of Jewellery," Mr. Streeter has done good service to the public by stating plainly the relative value of the different qualities of gold, and it is from this work the following quotations are taken.

HOW JEWELLERY IS MADE BY MACHINERY.

Mr. Streeter says, "I now proceed to describe the manufacture of golden ornaments; and that this may be the more readily understood, I propose to trace the construction of a bracelet. Suppose a skilled workman be required to fashion one by hand, the process would be this: the necessary quantity of gold having been weighed out—the gold would probably be in a piece of about a quarter of an inch in thickness—it would first be hammered to the required tenuity; then, having cut it into strips, the artificer would construct the flat portion of the bracelet which goes round the wrist, and make the

chenille or raised edge; then he would model the centre ornament by means of the hammer and chisel, and cut out the beads and fasten them on; lastly, he would solder the various parts together, and add the joint and snap.

"The construction would of course in this way occupy much time, and as it could only be accomplished by a skilful workman, the bracelet must necessarily cost a high price.

"But now let us see what machinery can do to lessen both labour and price. In the first place, the gold, instead of being hammered into the required thickness, is passed through the steam rolling machine (*a*, Fig. 527), and can be pressed out to any extent in a few minutes. It is then with the greatest

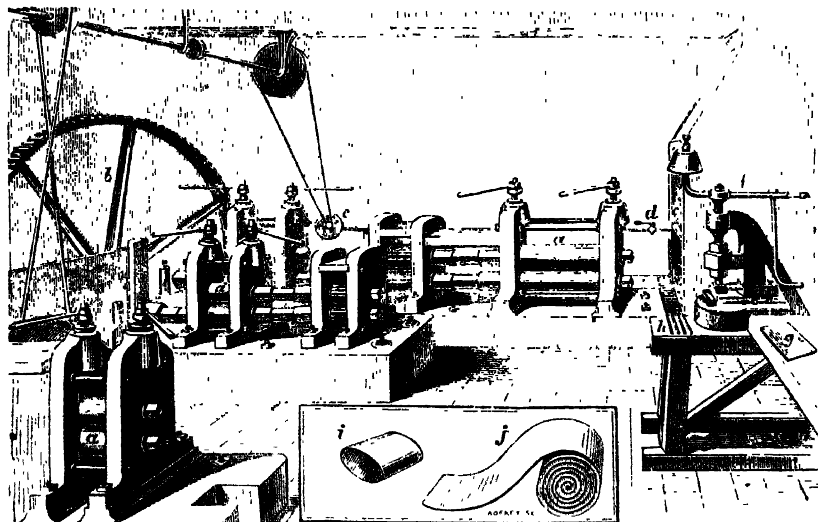
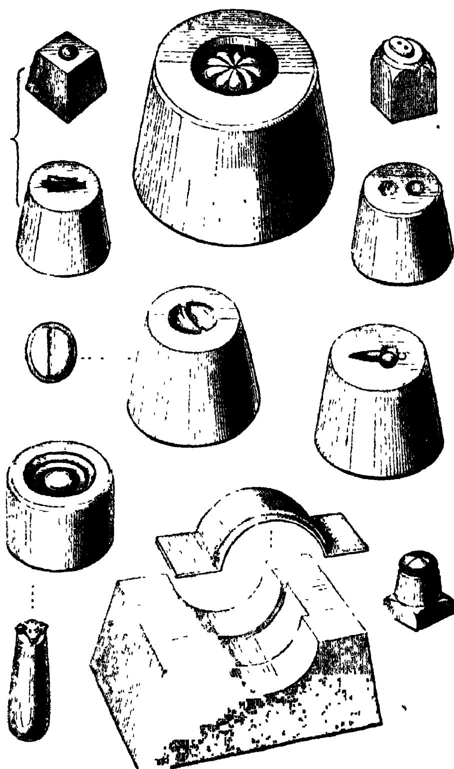


FIG. 527.

a a a, rollers; *b*, steam engine; *c*, bellows; *d*, tap to regulate supply of air to furnace; *e*, furnace; *f*, cutting machine; *g*, plate of rolled gold; *h*, thin slips of gold cut from plate; *i*, cake of gold; *j*, the same rolled.

rapidity cut into strips by the cutting press (*f*, Fig. 527). A die (Fig. 528) having been prepared (and every one who has a monogram for his note-paper knows how quickly and inexpensively dies are made), a strip of the gold is put into the "monkey press," an apparatus of considerable power, and with two separate blows the two halves of the bracelet are stamped out. Meanwhile, by means of another die and *press of less power*, the centre ornament is with equal facility formed; and all that remains for the workman to do by hand is to joint the bracelet and put on the snap, and to polish it.

"In the ornamentation of jewellery gold wire of different degrees of fineness is used. This wire is made as follows: the gold is first cut into strips by means of the cutting press. Each strip is then forcibly drawn through an aperture in a steel plate, which rounds it and forms it into wire. This is again passed through apertures, smaller and smaller, until the required size is obtained. These plates are called "gauges," and are capable of attenuating wire to any extent. It requires considerable power to force the strips through the



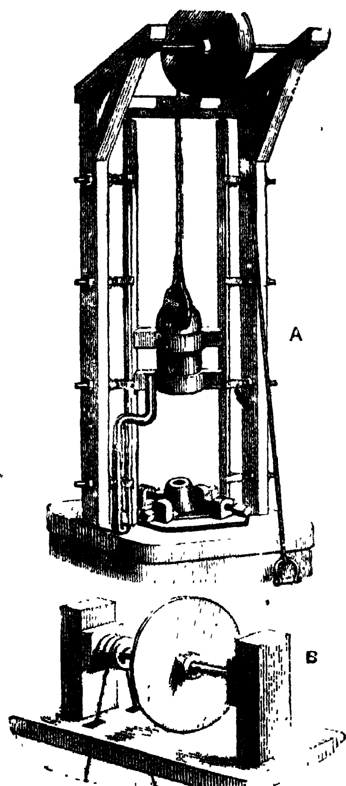


FIG. 529.—*The Monkey Press.*

FIG. 528.

FIG. 530.—*The Lapping Machine, used for polishing the bright parts of Gold Ornaments.*

gauges, and this power is obtained by means of the "drawbench." This description refers, of course, to plain wire only; ornamental wires have to undergo an additional process.

"A bracelet would take a skilled workman *six* days to make by hand, whilst, with the aid of the machinery I have described, the same ornament, including the necessary hand-work, such as jointing, polishing, &c., can be made in *two* days.

"From the above brief description it will be readily understood how it is that really good jewellery may be obtained at a comparatively small cost, and yet a good profit may be had by the vendor. The price of the gold contained in any one ornament is the same, both to the jeweller and to the purchaser; the profit to the former is—or ought to be—derived from the workmanship, and the more quickly he can manufacture such articles, the cheaper he can sell them, getting for himself a fair profit, and giving to the public advantages which they could not have had under the old system.

"Pure gold is represented by the figures 24, and is called 24-carat gold; but

it is seldom to be procured in a state of perfect purity, as it requires a long chemical process so to obtain it, which adds so much to its cost that it is too expensive for commercial purposes. That which is called 24-carat is really only $23\frac{1}{2}$ or $\frac{7}{8}$, which is quite good enough for all practical purposes. This being purchased by the manufacturing jeweller, is alloyed according to his taste or conscience; which latter, I am afraid, is not always of the most sensitive nature."

TABLE SHOWING THE DIFFERENT QUALITIES OF GOLD MANUFACTURED IN DIFFERENT PARTS OF THE WORLD.

		Carat.		£	s.	d.		Carat.		£	s.	d.
England	From	1	worth	0	3	6	to	22	worth	3	17	$10\frac{1}{2}$
France	"	18	"	3	3	$8\frac{1}{2}$	Only common by special permission.					
Denmark	"	18	"	3	3	$8\frac{1}{2}$						
Baden	"	14	"	2	9	$6\frac{1}{2}$						
Germany (all States) .	"	12	"	2	2	$5\frac{1}{2}$	to	15	worth	2	13	1
Russia	"	15	"	2	13	1	"	22	"	3	17	$10\frac{1}{2}$
Austria	"	10	"	1	15	$4\frac{1}{2}$	"	18	"	3	3	$8\frac{1}{2}$
Italy	"	12	"	2	2	$5\frac{1}{2}$	"	22	"	3	17	$10\frac{1}{2}$
Holland	"	4	"	0	14	2	"	22	"	3	17	$10\frac{1}{2}$
Africa	"	23	"	4	1	6						
India	"	22	"	3	17	$10\frac{1}{2}$	"	$23\frac{1}{2}$	"	4	3	$1\frac{1}{2}$
Rome	All	18	"	3	3	$8\frac{1}{2}$						
United States . .	From	1	"	0	3	6	"	18	"	3	3	$8\frac{1}{2}$
Norway and Sweden .	All	18	"	3	3	$8\frac{1}{2}$						
Belgium	From	18	"	3	3	$8\frac{1}{2}$	"	22	"	3	17	$10\frac{1}{2}$
Spain	All	18	"	3	3	$8\frac{1}{2}$						
Switzerland	"	18	"	3	3	$8\frac{1}{2}$						
Geneva	From	14	"	2	9	$6\frac{1}{2}$	Watch-cases only.					
China	"	16	"	2	16	$7\frac{1}{2}$	to	$23\frac{3}{4}$	worth	4	4	0
Japan	"	18	"	3	3	$8\frac{1}{2}$	"	$23\frac{3}{4}$	"	4	4	0
Brazil	All	18	"	3	3	$8\frac{1}{2}$						
Hamburg	From	$13\frac{1}{2}$	"	2	11	$3\frac{1}{2}$	"	18	"	3	3	$8\frac{1}{2}$
Turkey	"	18	"	3	3	$8\frac{1}{2}$						
Greece	"	10	"	1	15	$4\frac{1}{4}$	"	16	"	2	16	$7\frac{1}{2}$
Persia	"	3	"	0	10	$7\frac{1}{2}$	"	$23\frac{1}{2}$	"	4	3	$1\frac{1}{2}$
Egypt	"	18	"	3	3	$8\frac{1}{2}$						
Rio Janeiro .	Imported from	1	"	0	3	6	"	22	"	3	17	$10\frac{1}{2}$
Chili . .	" "	1	"	0	3	6	"	22	"	3	17	$10\frac{1}{2}$
Peru . .	" "	1	"	0	3	6	"	22	"	3	17	$10\frac{1}{2}$
Siam . .	Nearly pure, fine work.											
Australia .	Same as England, except that made up from the diggings.											
Mexico . .	Principal manufacture fine.											

Any quality is allowed to be imported into these countries.

"The kinds of gold best adapted for manufacturing purposes are 18 or 16-carat. Trinkets made of these qualities not only keep their shape and hardness; and allow of designs of delicate and intricate workmanship, but are of fair proportionate value to the purchasers. What is called standard or guinea gold is made of twenty-two parts pure gold and two of alloy. Of this quality gold coins are made.

"The relative values are as follows:

		£	s.	d				£	s.	d.	
22-carat gold	is worth	3	17	10½	per oz.	8-carat gold	is worth	1	8	3¾	per oz.
18 "	"	3	3	8½	"	6		1	1	2½	"
16 "	"	2	16	7½	"	4		0	14	2	"
14 "	"	2	9	6½	"	2		0	7	1	"
10 "	"	1	15	4¼	"	1		0	3	6	"
9 "	"	1	11	10	"						

"Until the reign of George the Third the standard of gold was fixed at 22 carats, that is, of twenty-two parts of the pure metal and two of alloy. This was the quality of the gold coin. At that time also goldsmiths were bound by law to make no 'vessel or ware' save of the standard. During this reign, however, an Act of Parliament was passed permitting a lower standard, viz., 18 carats (or eighteen parts pure gold and six alloy), to be used in the manufacture of gold ornaments or jewellery; and, in order that the public might be protected against fraud, the Legislature conferred upon the Goldsmiths' Company power to examine the quality of gold in course of manufacture found in the different workshops; to break up all that was of an inferior kind; and to punish the offenders by fines. The said Company was also authorized to compel manufacturers to bring their articles to the Hall to be assayed and stamped according to their quality or value.

"After a while, however, exceptions to this rule were made, and a compulsory mark was only required upon the following: wedding-rings, 22-carat; mourning rings, 18 or 22-carat; watch-cases, from 9 to 22-carat.

"Thus it soon became the practice to manufacture other articles in gold of a most inferior quality, so that at present it is impossible without the guarantee of a respectable jeweller to know what you are buying."

Gold does not tarnish when exposed to damp or dry air: the dust and dirt which collect on gilt iron railings suggests the idea that the gold itself is affected; but this is not the case, as even sulphur, which blackens silver so quickly in London and other large cities, has no power to alter the surface of gold.

There are two compounds of gold and oxygen: the aurous oxide or suboxide of gold (Au_2O), and the auric oxide or peroxide (Au_2O_3).

The salts of gold worthy of note are the sulphide of gold (Au_4S_4); the two chlorides of gold, the protochloride ($AuCl$) and the trichloride ($AuCl_3$), and the hydrated double stannate of gold and tin, or "*purple of Cassius*" ($SnAu_2Sn_2O_6, 4H_2O$), used to impart the ruby red to glass and the rose colour to porcelain.

ORGANIC CHEMISTRY.

FROM the air, water, and various natural substances contained in the earth, we derive all the bodies that have been discussed in the list of non-metallic and metallic elements. These elements have been spoken of as if they belonged only to dead matter: it is, however, clear that some of these elements are operated upon, and are only built up into complex organic compounds, by the influence of vitality. Thus it is we have organized matter, such as woody fibre, cellulin, bone, muscle, and nerve matter. All these things have been connected with life: the chemist could not take the elements of which they are composed and put them together again, to re-form muscle or nerve matter. Analysis, but not synthesis, is the ruling power in organic chemistry. There are, however, organic compounds that will crystallize, and which possess a constant and exact composition, and yet it cannot be said they are organized.

The alkaloids of the cinchonas, or those contained in opium, oxalic acid, sugar, the alkaloids of coffee, tea, chocolate, are all examples of organic compounds, although they do not betray any organic structure such as would be seen with the aid of a microscope in the various tissues or parts of a living animal or plant.

The field of inquiry included under the head of organic chemistry is, therefore, of vast extent: it not only treats of the nutrition of animals and vegetables, but discusses elaborately the solids and fluids and bases of animal origin. It analyses and discovers the nature and properties of resins, gums, colouring matter, essential oils, essences, the alkaloids, the fatty and vegetable acids, and organic acids in general; products obtained from sugar, alcohol, glycerine; the ethers; and all the interesting changes brought about by fermentation. In the limited space at our command the analysis of organic bodies only can be briefly alluded to. In the analysis of an inorganic salt, such as cupric sulphate, it is always usual to speak of the proximate and ultimate constituents: the proximate constituents would be oxide of copper, sulphuric acid, and water; the ultimate elements, copper, oxygen, sulphur, and hydrogen. So it is with organic compounds: the coffee-berry consists (according to Payen) of the following proximate constituents:

Ligneous tissue
Hygroscopic water
Fixed fatty matter
Gum, sugar, and a vegetable acid
Azotized matter analogous to legumine
Free caffeine
Compound of caffeine with potash and chlorogenic (caffeic) acid
Aromatic essential oil
Solid fatty essence
Saline matters.

The whole reduced to ultimate elements would be represented by carbon, oxygen, hydrogen, nitrogen, potassium, and phosphorus.

The analysis of an organic body is, therefore, commenced by a careful separation of each proximate constituent, and these are subjected to a separate investigation with respect to their individual properties, and finally to an ultimate analysis. The organic substance must be carefully dried, and, of course, should be free from all impurity or admixture with any other organic body; and as the ultimate composition can only be obtained by its so-called "destruction," or rather combustion, the material (say sugar) is placed in a glass tube of hard Bohemian glass, 15 in. long and ½ in. in diameter, as marked D, E, F, in Fig. 531, and this is laid in a sheet-iron trough or furnace, A B, in which red-hot charcoal is carefully placed. If sugar alone were put in the tube, destructive distillation only would take place, and the ultimate analysis could not be carried out to the end; it is usual, therefore, to mix with the organic substance some material that will afford oxygen. The body usually employed for this

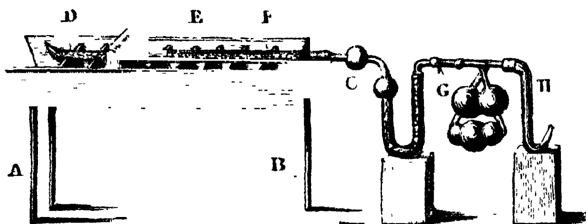


FIG. 531.—*Apparatus for Organic Analysis.*

purpose is oxide of copper, and numerous precautions are taken not only in weighing out the dried substance under examination, but in mixing it with the oxide of copper, and finally placing it into the combustion-tube.

Sugar consists of carbon, oxygen, and hydrogen, and is resolved into water and carbonic acid when heated with oxide of copper. To separate the water, the glass bulb C, with a tube containing chloride of calcium, is attached to the combustion-tube, and receives and retains the water, whilst the carbonic acid is absorbed by a solution of potash of a specific gravity of from 1·25 to 1·27 in the bulb-tube, G; beyond the potash solution bulb is another tube, H, containing fragments of hydrate of potash, which arrests any moisture and carbonic acid that may pass the dessicating tube and potash bulbs. The careful and patient weighings of the combustion tube against the condensing tube and potash bulb supply data which the chemist works into the formula representing the substance under examination.

The student who desires to become a proficient in the analysis of organic bodies should consult Dr. Miller's "Elements of Chemistry," or Liebig's "Handbook of Organic Analysis," and after working upon sugar until his figures are constant, he may then go on to the analysis of organic bodies containing nitrogen. Here again another series of precautions must be taken, which are fully described in the works already alluded to.

In the various kinds of organic analysis the ingenuity of the chemist is taxed to originate tubes of different shapes to answer special purposes. (See Fig. 532.)

When it is necessary to restore the whole tube system used in organic

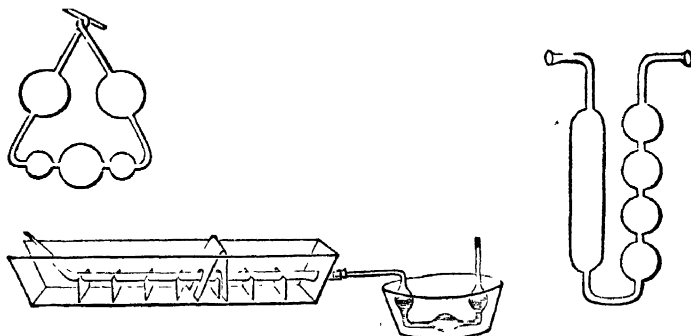


FIG. 532.—*Tubes and bulbs that may be employed in Organic Analysis.*

analysis to the normal condition, so that each tube and bulb is filled with atmospheric air, an aspirator is attached. The vessel C, Fig. 533, is called the aspirator, because it sucks or draws the atmospheric air into the tubes.

The combination of organic bodies may also be effected with pure oxygen gas, assisted by Hoffman's furnace, in which the heat is produced by burning gas. Forty years ago, the teacher (Mr. John Thomas Cooper) under whom the writer studied, invented a very excellent apparatus for organic analysis, in which the heat was produced by the combustion of alcohol.

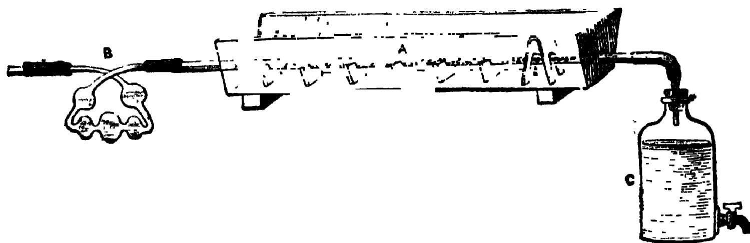


FIG. 533.

A, the combustion-tube; D, furnace; B, potash bulb; C, bottle full of water: whilst the latter runs out, air must pass through the various tubes, and as they were weighed in the first place when they contained air, so the last weighing would be incorrect unless the various tubes contained the same gaseous medium.

The facts supplied by the careful and plodding experiments of numerous chemists in organic chemistry have supplied Laurent, Liebig, Gerhardt, and their followers with the facts which have created a new nomenclature in organic chemistry, extending to the whole range of chemical science, inorganic as well as organic.

Contributions to, and knowledge of, organic decomposition are always valuable; and as a sequel to this brief article may be noticed the curious experiments lately made by Dr. B. Richardson, F.R.S., which are fully detailed in the "Medical Times and Gazette," 9th January, 1869, as follows:

Exposure of Animal Substances to Water Gas at a High Temperature—340° F.

The learned author says :

"I woke one day not long since from sleep with a dream before me in wonderful reality. I thought I had been at work in the laboratory subjecting animal structures to the same process as that to which the dentist subjects vulcanized india-rubber when he is making vulcanite base. The dream, childish as it was, as coming from no traceable line of connected thought, seemed to me to be worth accepting as a hint to positive work, and so I followed up the ideal by the real, with results which I propose to describe to-day as simply as I have read them.

"We take for our purpose the common vulcanizing apparatus used by the dentist, and depicted in the diagram (Fig 534). It is a very strong chamber

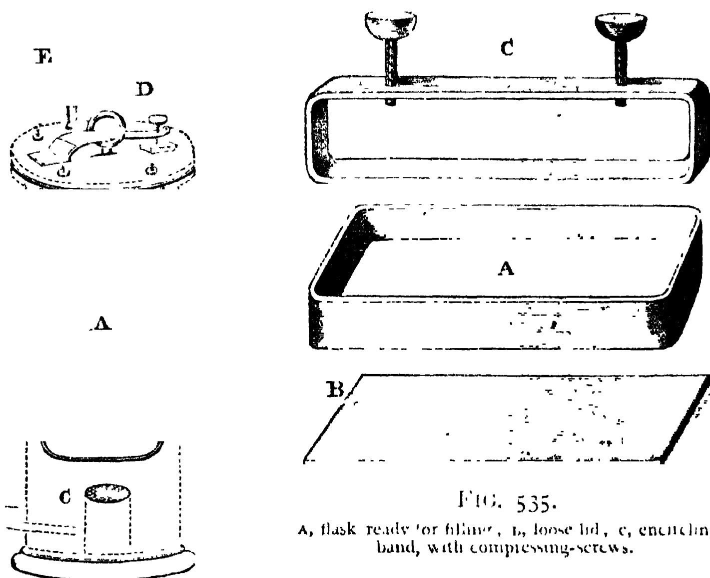


Fig. 535.
A, flask ready for filling, B, loose lid, C, encircling band, with compressing-screws.

Fig. 534.
A, iron cylinder; B, stove, C, gas burner; D, lid with safety-valve; E, thermometer.

of iron, enclosed in an iron case or stove, with a series of gas burners at the lower part of the stove. The iron chamber, which receives the substances to be operated upon, is heated by the burners. It is furnished with a heavy iron lid with binding-screws, a safety-valve, and a tube for holding mercury, in which a thermometer is inserted. When we are about to use the apparatus, we place our specimens in the chamber with a little water. The apparatus I have used, and which has been kindly lent me by my good friend and

neighbour, Mr. Ballard, has a chamber 10 inches deep and 5 inches in diameter. Six or eight fluid ounces of water in the chamber answer very well for one series of experiments; but the quantity may be varied, by which different results may be obtained. Having, then, placed our specimens and the water in the iron chamber, we screw on the lid firmly, interposing what may be called a washer of brown paper between the lid and the chamber at the part where they touch; we screw down the safety-valve, interposing beween it and the small opening it covers also a layer of brown paper; we put the thermometer into the mercury, light the gas, and watch the rise in the thermometer up to the point of heat required. The necessary degree of heat obtained, the gas is turned a little down and moderated until the mercury remains steadily at one point, and the experiment is continued for whatever length of time may be desired.

"The specimens of animal structures to be experimented on may be introduced into the chamber in different ways. In some cases we place the specimen directly in the chamber in or above the water; in other cases we put it in an iron flask filled with wet plaster of Paris, lime, carbonate of lime, powdered carbon, clay, powdered Portland stone, or other substance, and subject the whole to pressure by compressing-screws. I have constructed a very convenient iron flask for this purpose. It consists of a framework of iron, with two plates of iron to make a false top and bottom. The frame laid on the lower plate forms a flask, and into it the plaster of Paris, or clay, or sand, or carbon, moistened with water, is placed, with the specimen embedded. Then the upper plate of iron is dropped on, an encircling band of iron is passed over the whole lengthways, two screws in this band are brought forcibly down on the upper plate of the box, and thus the specimen, with the substance in which it is buried, is firmly encased. The iron flask, in this way arranged, is now ready to be placed in the chamber. The advantage of this flask is, that when the exposure to heat is completed and the metal is cooled down, on setting free the iron band the false top and bottom can be removed, and the specimen can be cut out with a small keyhole-saw from its iron framework. The flask is depicted in the diagram (Fig. 535) in parts.

"Having stated these preliminaries, I pass to describe some of the results which up to this time have been obtained.

"BLOOD.

"Into the chamber of the apparatus a portion of blood-clot, from the blood of an ox, was placed on a shelf with 8 oz. of water beneath. The lid of the chamber was firmly adjusted, the heat was raised to 340° F., and was sustained at that degree for one hour and a half. The heat was then withdrawn, and some hours were allowed for cooling. On opening the iron chamber, the blood was found almost unaltered in shape, but altogether changed in consistence and structure. It felt like simple caoutchouc, but broke with a bright surface like Spanish liquorice. The natural characteristics of the blood were lost, and on gentle drying the mass became brittle, closely resembling jet. A specimen of blood thus treated has been examined by my friend Dr. Sedgwick, who reports upon, it that it 'was a bright black, friable, jet-like material. Gently rubbed down with a little distilled water, it formed a reddish-brown fluid, which under the microscope was seen to consist of a coloured liquid, and reddish granular masses of various sizes. Very many were about one-sixth the size of a blood corpuscle, reddish-brown, and very irregular in shape. As the

solution dried, one or two irregularly hexagonal crystals made their appearance. The substance, after twenty-four hours' soaking, was partially soluble in strong solution of ammonia, very slightly in distilled water, and hardly at all in dilute hydrochloric acid and in methylic alcohol; it was untouched in ethylic ether and in chloroform.'

"Into the iron box or flask plaster of Paris was poured in the fluid state, and a clot of fresh blood was immersed in the plaster. The lid was placed on the box, and when the plaster had set firmly, the whole was placed in the chamber with 6 oz. of water. The temperature was raised to 340°, and sustained for an hour and a half. On breaking up the plaster, after cooling, the blood was found in the same state as that named in the experiment described above.

"ALBUMEN.

"An egg was placed in the iron flask and surrounded with plaster of Paris in the fluid condition. When the plaster was entirely set, the flask was put into the chamber with 6 oz. of water, the temperature was raised to 340°, and was sustained for an hour and a half. After cooling, which was very rapidly effected by immersing the flask in cold water, I found, on removing the egg, that the shell was nearly full of a beautiful transparent golden or amber-coloured fluid, very thin, and running like dissolved gelatine. In the course of a few hours this fluid was slightly gelatinized. The membrane lining the shell was detached, but not destroyed; the shell was dry, brittle, and firmly attached to the surrounding plaster. The experiment was repeated with another egg, but was modified by allowing the apparatus to cool very slowly in the air at 60°. On breaking the plaster, and cutting through the egg, no fluid was found, but in the centre a soft yellow substance (probably the yolk), about the size of a hazel nut, and slightly glistening on the surface. On gently drying this substance, it became firm, retaining its colour, and looking like amber, but not so hard.

"THE BODY OF A TOAD IN CARBON.

"The iron flask was partly filled with fluid plaster of Paris. On this layer a bed of vegetable carbon, in fine powder, was laid, and the body of a toad recently dead was buried in it. The carbon mound was next enclosed in plaster; the flask was closed, and half an hour later it was placed in the iron chamber with 10 oz. of water. The temperature was first raised to 350° F., but was brought down to 340°, and was retained at this degree for an hour and forty minutes. The gas was then turned off, and the apparatus was allowed to cool slowly. On opening the flask, the body of the animal was found to be altogether destroyed, and so mixed with the carbon that no part of it could be defined.

"THE BODY OF A FROG IN SAND.

"The body of a frog recently dead was buried within the iron flask, in moist fine sand compressed with moderate firmness. The flask was then put into the iron chamber, with 6 oz. of water, and the temperature was raised to 340° F., and sustained for an hour and a half. The flask was opened twelve hours afterwards, and the results of the experiment were found to be nearly the same as when carbon was employed. The animal was destroyed, and no distinct organ or structure could be distinguished.

"BODY OF A FROG IN PLASTER OF PARIS.

"Fluid plaster of Paris was poured into the iron flask until the flask was half full. The body of a frog recently dead was now laid on the plaster, and allowed to mould itself to it. When the plaster had become rather firm, another quantity of fluid plaster was poured in, so as to bury the frog completely and fill the flask. An hour later, the flask, which had been closed with pressure, was placed in the iron chamber. The temperature was raised to 340° F., and sustained for two hours. Twelve hours later the flask was opened, and a mould of the frog was found, the organic soft parts of the body having been destroyed. At the lower part, in the centre, was a black spot: the spot consisted of blood which had gravitated to the lowest part. Besides this, there was a little *débris* of earthy part of bone within the mould. The impression of the body was beautifully marked in the plaster.

"BODY OF A FISH IN PLASTER AND ALUM.

"Some plaster of Paris, made into a fluid with water containing alum in solution, was poured into an iron flask until the flask was half filled. The body of a dead fish, a common sprat, was cut in halves transversely, the two

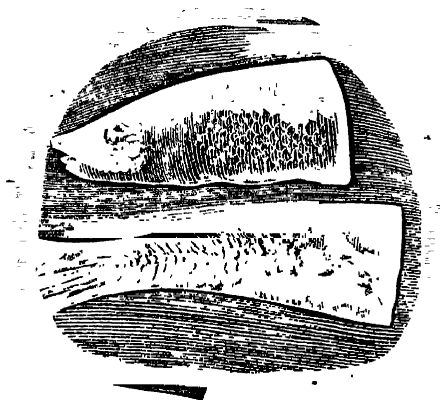


FIG. 536.—*Body of a Fish in Plaster and Alum.*

halves were laid upon the plaster, and the flask was filled up with fluid plaster and closed. When the plaster was firm, the flask was placed in the iron chamber, with 4 oz. of water, and the temperature was raised to 340° F., and was sustained at that degree for an hour. Twelve hours afterwards the flask was laid open, and the plaster cut in halves, when two moulds were found, one of the upper, the other of the lower half of the fish. The markings of the body of the fish were delineated on the mould; a small portion of bone (spinal) was left; a dark-coloured fine spot, surrounded by a shiny scaly substance, indicated the position of the eyeball; a little filamentous *débris* remained, consisting probably of the scaly covering of the animal."

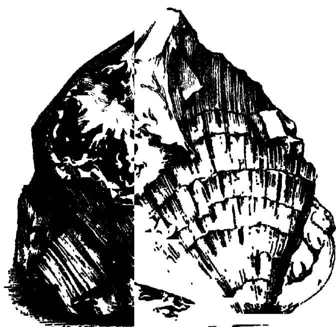
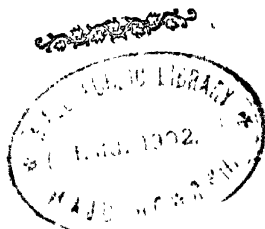


FIG. 537.—*Oyster-shell subjected to same process.*

After perusing the account of Dr. Richardson's experiments, the mind reverts to the formation of natural fossils, and the remarkable imitation of nature with pressure and heat, which produces these *quasi*-fossil moulds in plaster of Paris. Fossils have been spoken of as "the medals of creation;" who would dare (unless they were makers of artificial flint-head arrows) to imitate so closely? But the forgery in this case is an advance in science, and no doubt will assist the geologist and palæontologist to make speculations (this time) founded on actual experiment. In bringing this work to a conclusion, the writer desires it to be understood that he has endeavoured to fulfil a promise made in his first elementary work on science, and that was, to try to lead the youthful and unlearned reader further on in the pursuit of that science; the beginning of which, Sir Humphrey Davy said, is pleasure; its progress knowledge; its objects truth and utility.

It is said that Demosthenes first conceived his passion for eloquence upon hearing the orator Callistratus, and witnessing the applauses with which his performance was rewarded; that Tycho Brahé resolved to devote his life to astronomy in consequence of his witnessing, when a child, an eclipse of the sun. Surely amongst the thousands of young people who attend scientific lectures, there must be undeveloped geniuses who might, if they read and practise scientific experiments, become as useful and as celebrated as a DAVY, a FARADAY, or a WHEATSTONE!





INDEX.

LIGHT.

A.

LIGHT—*continued*

LIGHT—*continued.*

LIGHT—*continued*

LIGHT—*continued.*

HEAT.

HEAT—*continued*

HEAT—*continued.*

HEAT—*continued.*

HEAT—*continued.*

ELECTRICITY.

ELECTRICITY—*continued.*

ELECTRICITY—*continued.*

F.

ELECTRICITY—*continued.*

H.

ELECTRICITY—*continued.*

Q.

ELECTRICITY—*continued.*

R.

ELECTRICITY—*continued.*

MAGNETISM.

MAGNETISM—*continued*

MAGNETISM—*continued.*

MAGNETISM—*continued.*

MAGNETISM—*continued.*

MAGNETISM—*continued.*

PNEUMATICS.

PNEUMATICS—*continued*

PNEUMATICS—*continued.*

PNEUMATICS—*continued.*

PNEUMATICS—*continued.*

ACOUSTICS.

ACOUSTICS—*continued.*

ACOUSTICS—*continued.*

ACOUSTICS—*continued*

ACOUSTICS—*continued.*

CHEMISTRY.

A.

CHEMISTRY—*continued.*

B.

CHEMISTRY—*continued.*

CHEMISTRY—*continued.*

CHEMISTRY—*continued.*

CHEMISTRY—*continued.*

CHEMISTRY—*continued.*

CHEMISTRY—*continued.*

CHEMISTRY—*continued.*

CHEMISTRY.—*continued.*

CHEMISTRY—*continued.*

ORGANIC CHEMISTRY.


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